

AFTA Cycle-3 Telescope / WF_Channel Integrated Modeling Overview/Status

Dave Content

9-27-2013

Cycle-3 IM Team!

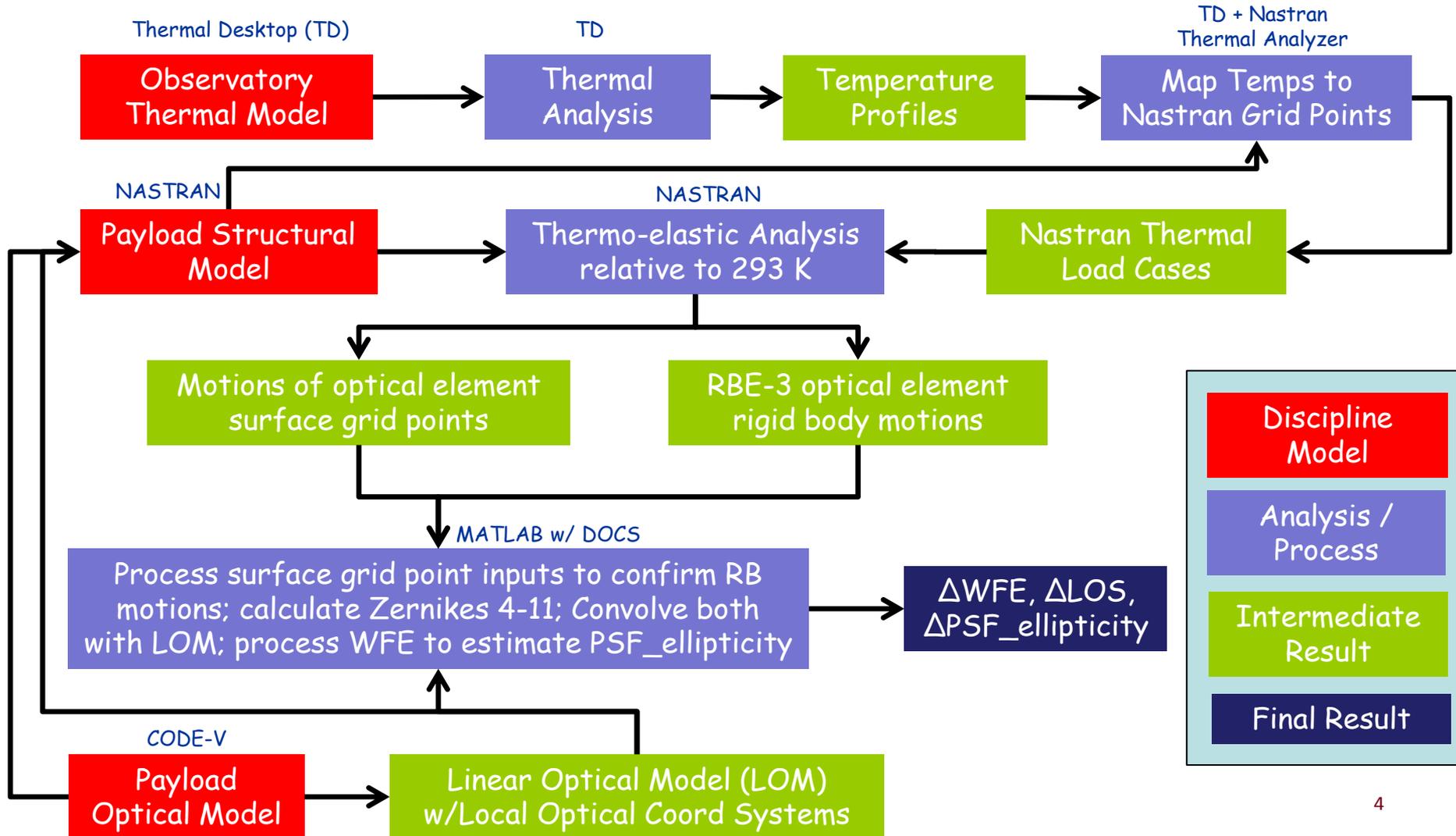
- Optical Model
 - Bert Pasquale, David Vaughnn
- Linear Optical Model (LOM) Generation
 - Joe Howard
- Structural Model/Analysis
 - Cory Powell
- Thermal Model/Analysis
 - Hume Peabody
- Structural/Thermal Mapping
 - Hume Peabody (TD)
 - Cory Powell (Nastran Thermal Analyzer linear interpolations)
- LOM-based WFE/LOS/PSF Results Generation
 - Carl Blaurock (NightSky Systems)
 - Alice Liu
- Instrument Systems
 - Cliff Jackson

Simplified Integrated Modeling Breakout (1 of 2)

STOP (Structural/Thermal Optical Performance) Analysis

- Generate a Linear Optical Model (LOM)
 - using Code-V to perturb each optical element in 6-dof rigid body (RB) motions as well as Zernikes 4-11
 - relate the size of the motion to the delta WFE and LOS resulting at the WF_channel exit pupil
- Apply a series of temperature profiles to a Nastran structural model which includes structural representations of ideal optical element surfaces/shapes in their ideal positions (as modeled in Code-V):
 - The series of thermal profiles can include cooldown from an initially aligned configuration at room temperature, or can be relative to an initial on-orbit reference configuration (assumed perfect if cooldown is ignored)
- Each thermal profile results in RB and surface node predicts for all optical elements:
 - 6-dof RB outputs are provided by RBE3 elements linked to the optical surface;
 - Surface node motions can be best fit to ideal optical shapes to x-check RB outputs, and Zernikes 4-11 are generated to represent the deformed shape
- The LOM is multiplied by the optical element RB motions and Zernikes for a given thermal profile, and the result is a prediction of the change in WFE/LOS relative to the reference thermal profile;
- Separate MatLab post-processing is used to assess the PSF ellipticity change for each thermal profile relative to the reference configuration.

STOP Small Perturbation Linear Analysis Flow



IM Analysis Goals for Cyc-3

- Take advantage of Cyc-3/Cyc-4 similarities to inform Cycle-4 design
 - Cyc-4 optical design has:
 - Simplified WFI optics and placed Telescope SM on-axis;
 - Reduced overlap of Coronagraph pick-off and WFI volumes;
 - Improved WF_channel optical tolerances to rigid body motions and deformations;
 - Preserved the same flow of WF_channel flat/powered optical elements as for Cyc-3
 - Instrument Carrier design is very similar, excepting changes to Instrument latch locations;
 - WFI Optical Bench is very similar, excepting changes to Carrier latch locations.
- The IM work selected for Cyc-3 is:
 - Perform STOP analysis; assess on-orbit WFE/LOS/PSF_ellip instability (cooldown Δ 'd out)
 - Define an Orbit/Attitude, provide hourly equilibrium thermal profile outputs for 24 hours, use them to produce 24 cooldown optical deformation outputs, difference the outputs relative to the first to eliminate cooldown effects, and assess WFE, LOS, and PSF_ellipticity instability due to thermal drifts.
 - Perform SVOP analysis to predict WFE/LOS/PSF_ellipticity instability due to vibration;
 - Perform realistic STOP cooldown with temp-dependent material properties to update WFE budget and assess possible need for warm offsets and/or cryo figuring;
 - Support ACWG with 24 hourly PM/SM deformed optics raw outputs, 24 PM/SM rigid body translations/rotations and Zernikes (providing Zernikes beyond 11 TBR), and 24 sets of Coronagraph Carrier latch point motions
 - 1g offload analysis

Telescope/WF_Chan Optical Configuration

➤ Optical Elements

- Primary Mirror (T1), Secondary Mirror (T2), Fold Flat 1 (F1), Tertiary Mirror (M3), Fold Flat 2 (F2)
 - Optical surface grid points defined, linked by RBE3 to Rigid Body node for each element
- Filter
 - Omitted from this analysis
- Focal Plane Assembly
 - Rigid Body only

➤ Linear Optical Model General Description

- Numerical sensitivity analysis using Matlab to drive Code V
- WFE and LOS sensitivity assessed at WF_Channel exit pupil

Payload Thermal Control Configuration

- Telescope (JPL-provided, updated in conjunction with GSFC feedback)
 - Thermal Set Points
 - PM, SM, Struts, Baffles, AMS, FMS: 272 to 268 K
 - OBA: 217 to 213 K
 - Set points are proportional control (we believe), zero power at high set point, max power at low set point, with linear variation in between.
- Carrier
 - Free-floating temperature
 - MLI wrap on all structure
 - No Instrument Carrier Enclosure “tent” blanket surrounding structure
- WF_Channel
 - Optical Bench
 - Passive Cold Bias with Optical Bench Radiator
 - PID thermal control at 165K on heat pipes at OB top and bottom plates
 - WF_Channel SCAs
 - Passive Cold Bias with SCA Radiator
 - PID thermal control at 117K on SCA Mosaic Plate
 - WF_Channel SCEs
 - PID thermal control at 165K on SCE Mounting Plate

Thermal Analysis Case Details

➤ Orbit and Attitude Case was drawn from a set of “hot” case configurations developed by C. Hirata, C. Jackson, and H. Peabody)

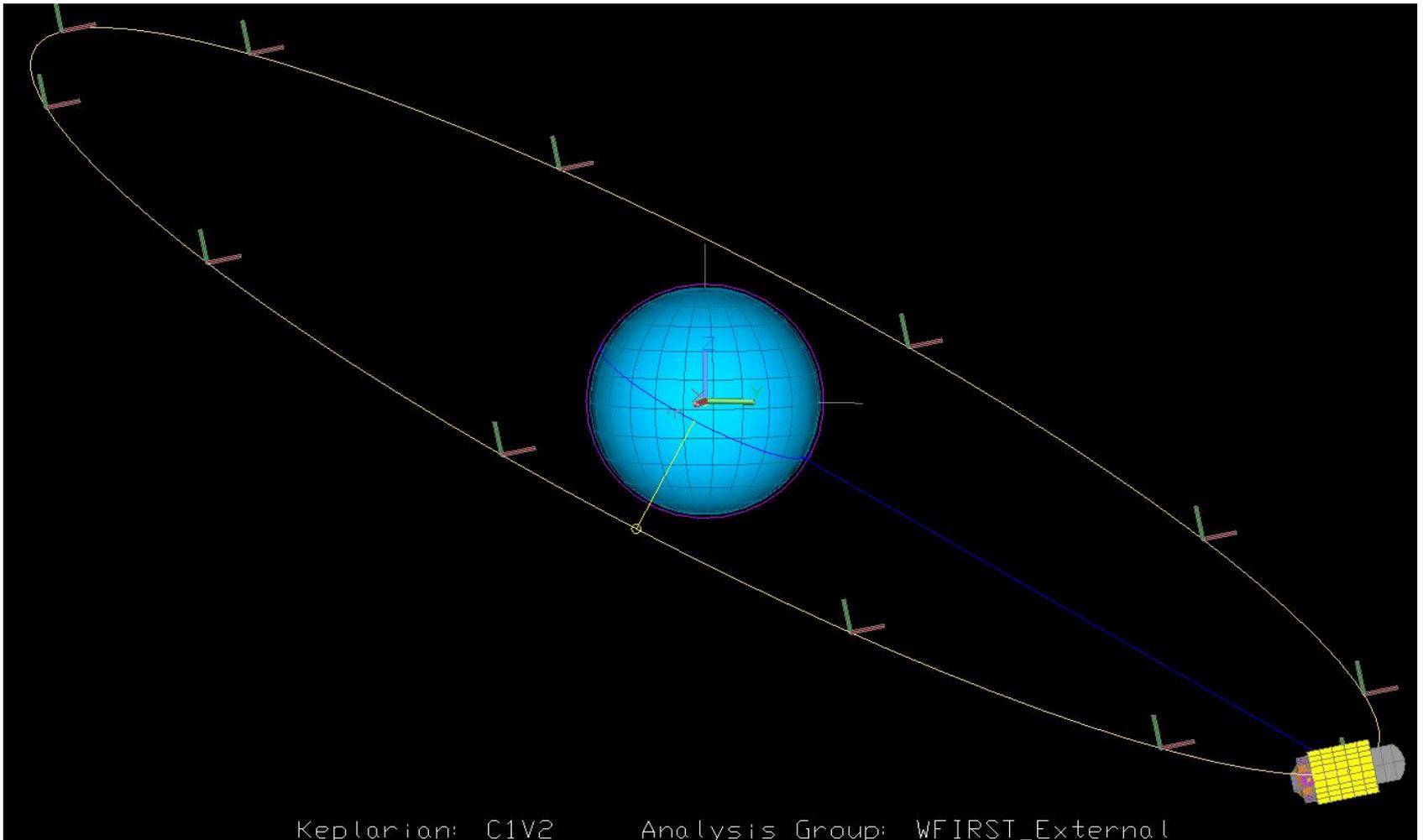
➤ Orbit

- 28.5° inclined GEO stationary orbit
- 175° RAAN
- 11° Beta Angle
 - Near Beta = 0, but no eclipse (April 1, 2023, 00:21 UTC)

➤ Attitude

- Sun normal to Solar Array
 - Pitch = 0, Roll = 0
 - Pitch/Roll extreme cases from C. Hirata have yet to be explored thermally
- Azimuth:
 - Selected by Chris Hirata to place the Telescope LOS 38.9° off the orbit plane, which is as close as is currently allowed given stray light constraints; Results in max variation in Earth load into the Telescope barrel;
 - Normal to WF_channel radiators is 33.92° off the orbit plane, which is very close to the minimum (27°) required by Chris Hirata for uL observations (April 2013 SDT Final Report); results in near max variation in Earth load on the WF_channel radiators (within 7% of 27° angle max radiator heat load)

STOP Analysis Orbit/Attitude Graphic



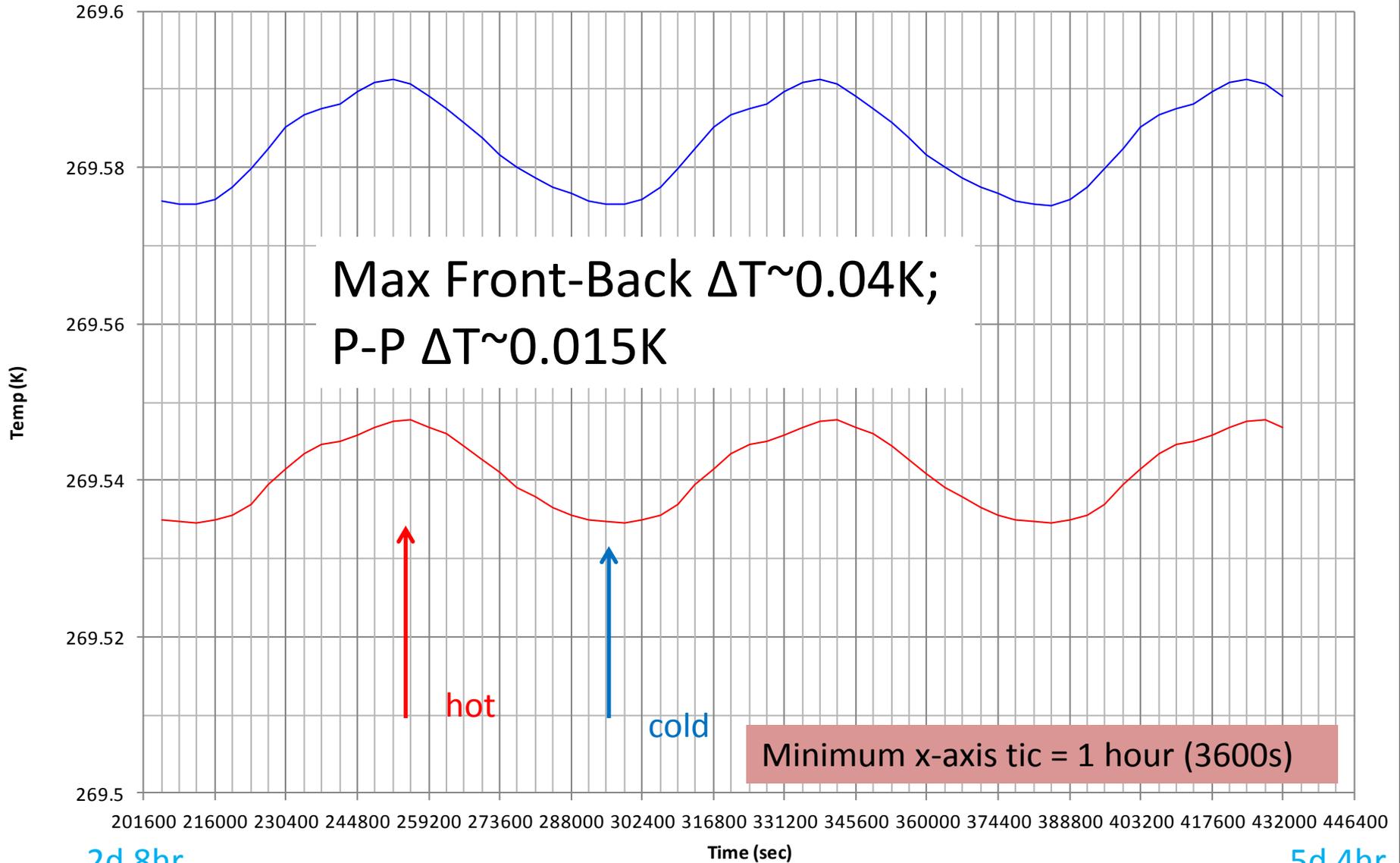
S/C "X" = red axis
S/C "Y" = green axis
S/C "Z" = blue axis (pointing to Sun)

View is from the Sun

WFIRST Primary Mirror - Front to Back

C1V2:PM_Front

C1V2:PM_Back



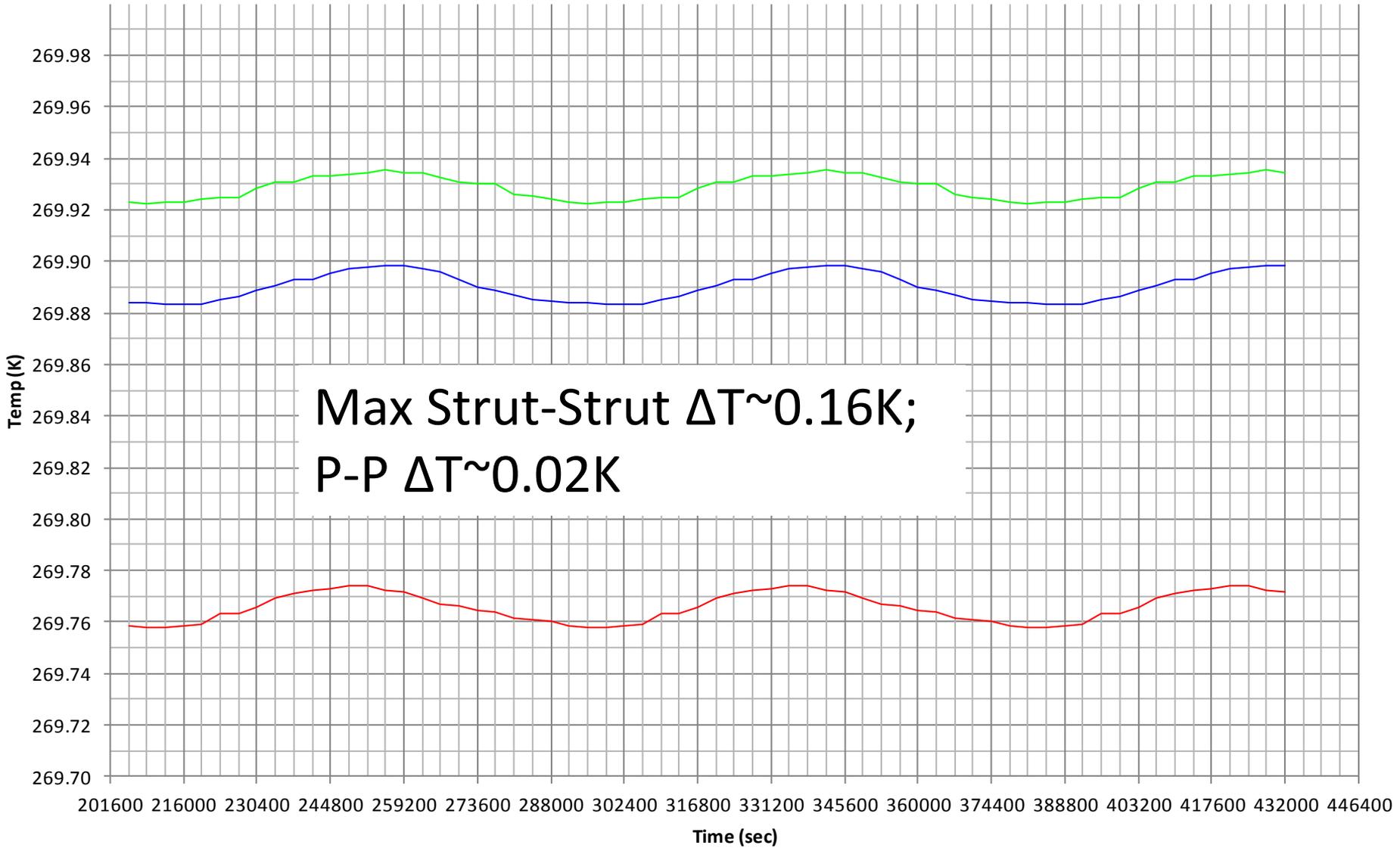
N.B. Later PM/SM Hot Pics at T=252000, Cold Pics at T=298800

WFIRST Primary Mirror - Mounts

C1V2:PM_Mount1

C1V2:PM_Mount2

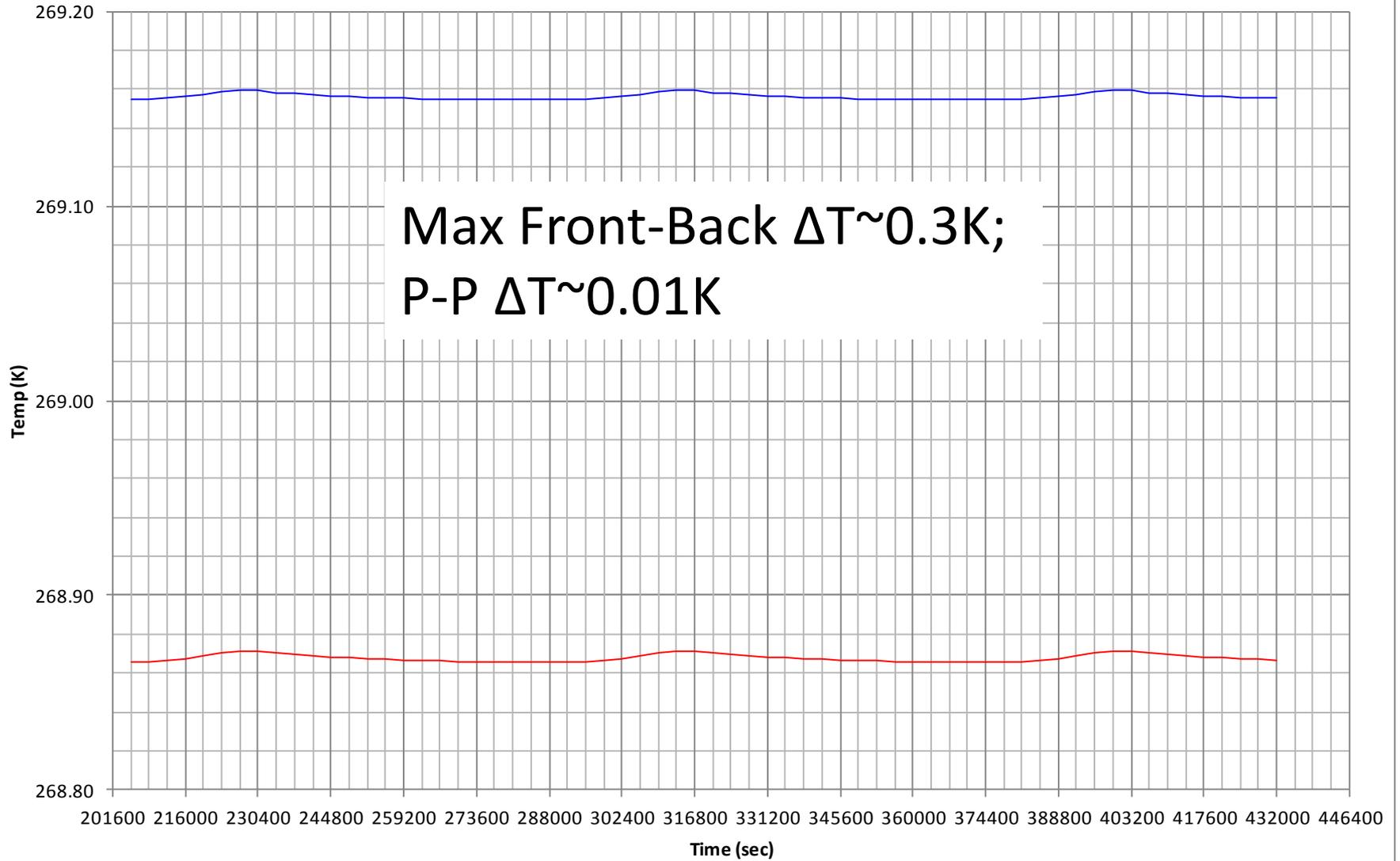
C1V2:PM_Mount3



WFIRST Secondary Mirror - Front to Back

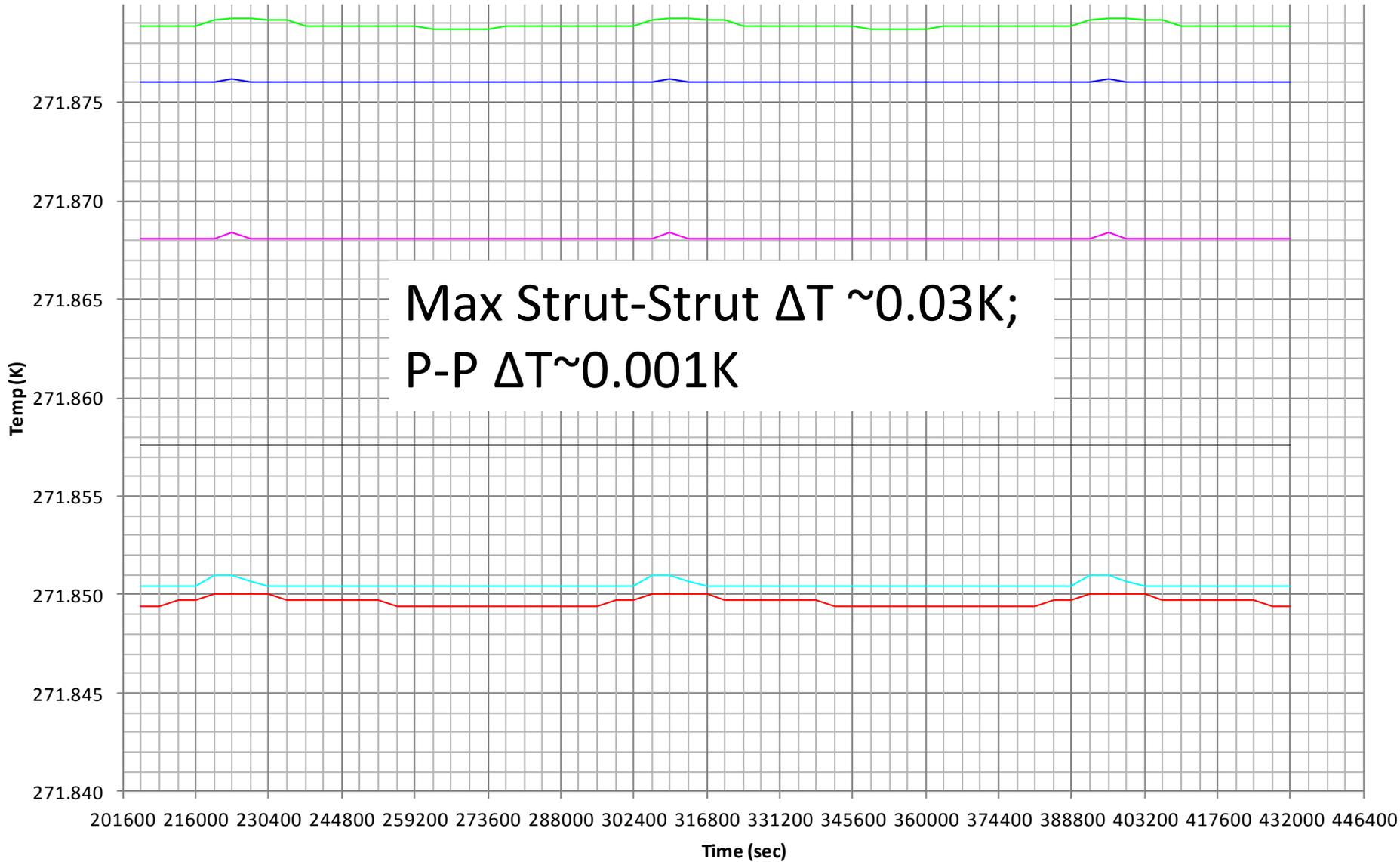
C1V2:SM_Front

C1V2:SM_Back

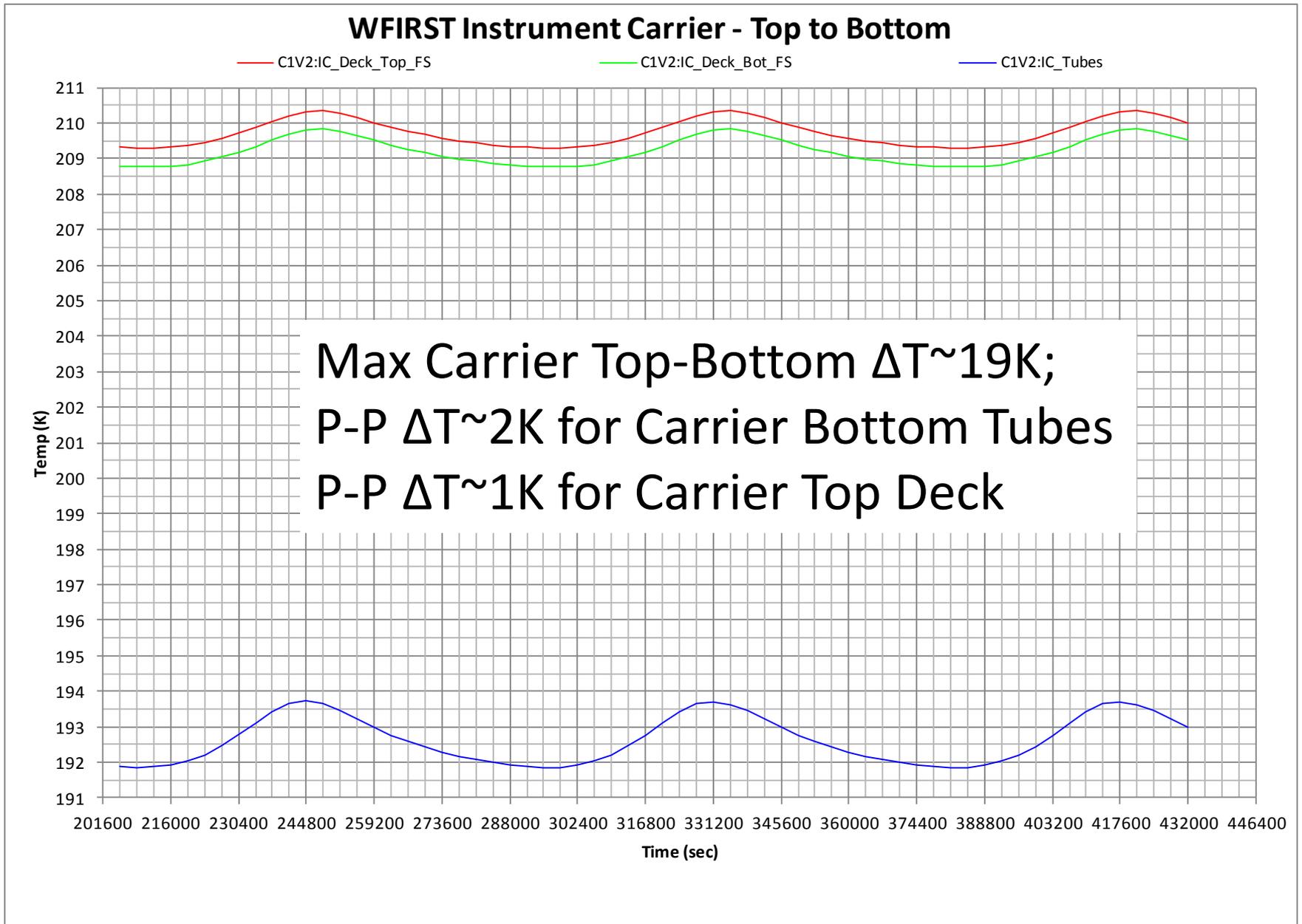


WFIRST Secondary Mirror Struts

C1V2:STRUT1 C1V2:STRUT2 C1V2:STRUT3 C1V2:STRUT4 C1V2:STRUT5 C1V2:STRUT6



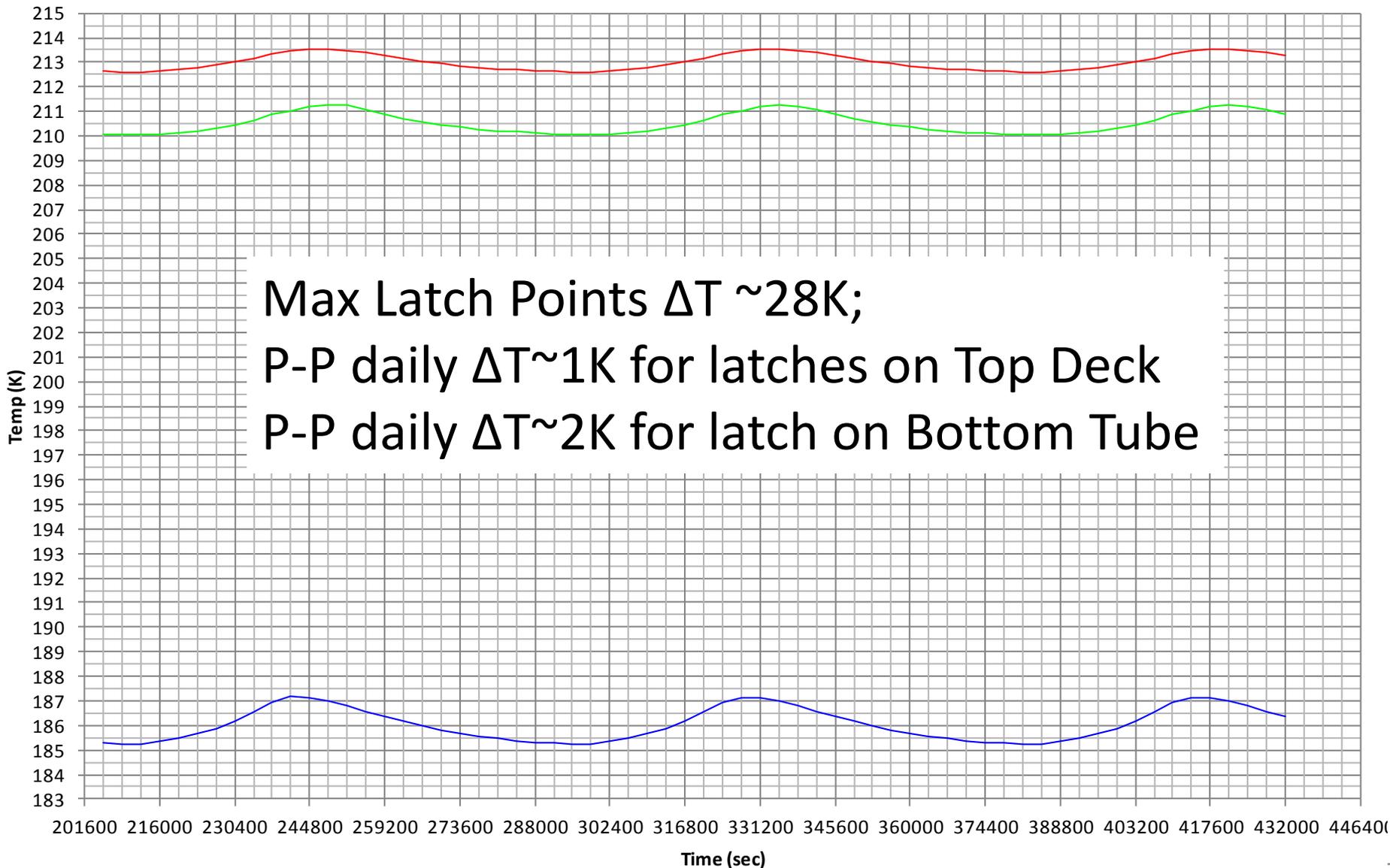
Note – IC in cycle3 does not yet have any heaters or thermal control!!



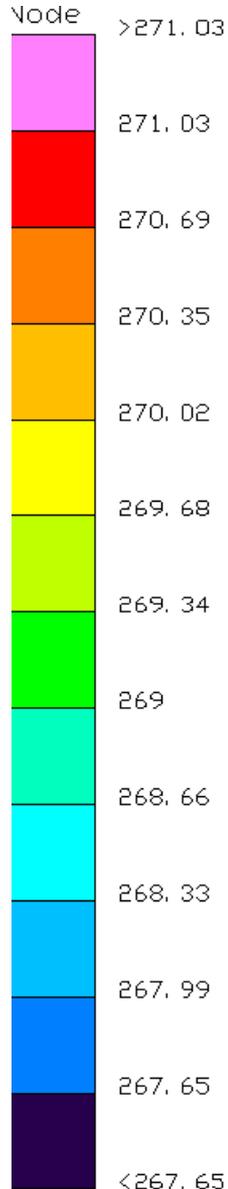
Note – IC in cycle3 does not yet have any heaters or thermal control!!

WFIRST Instrument Carrier - Coronagraph Latch Points

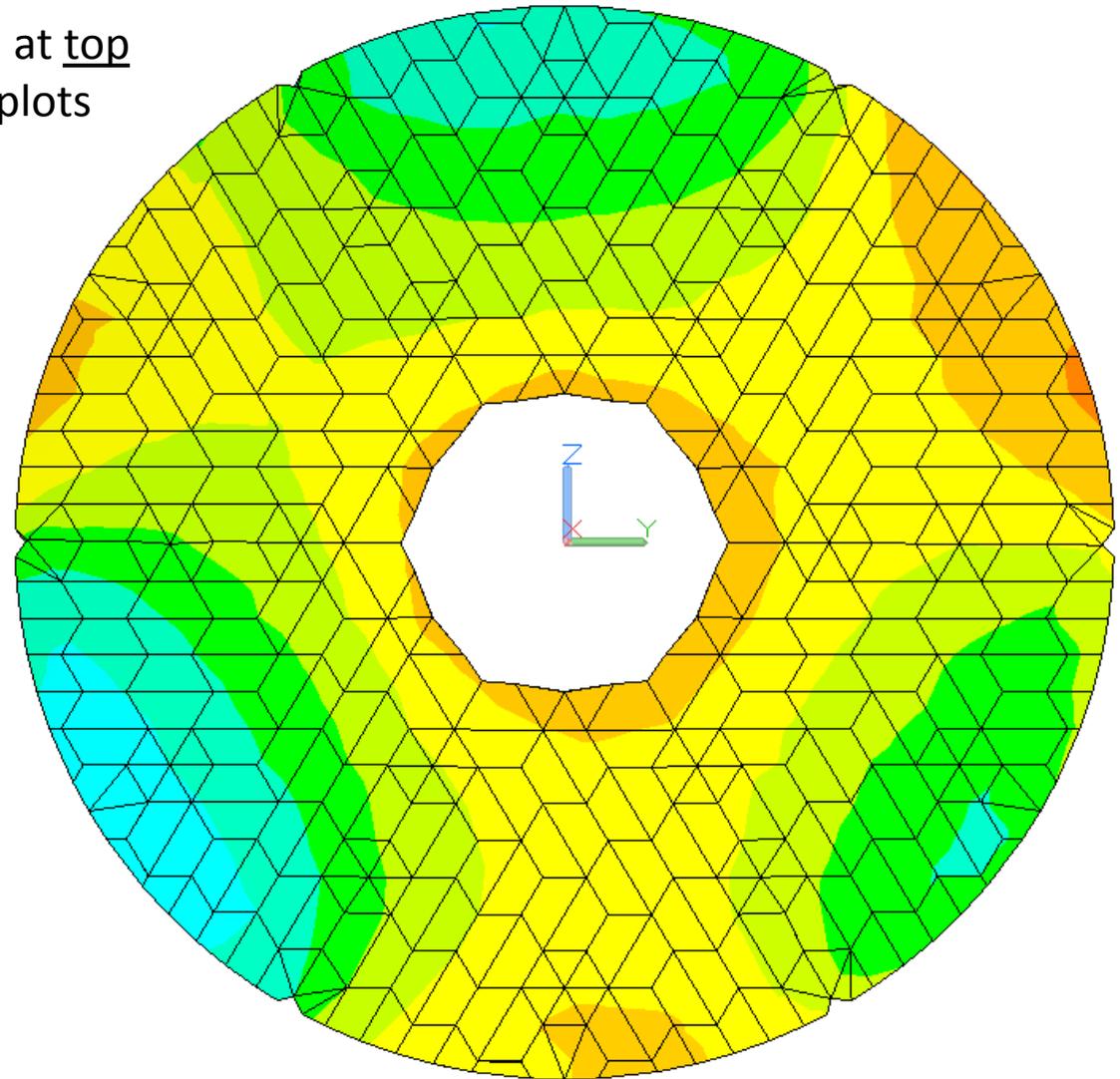
C1V2: +Z Coronagraph Latch Point - IC C1V2: -Z Coronagraph Latch Point - IC C1V2: -X Coronagraph Latch Point - IC



PM Front Orbital Hot Temp



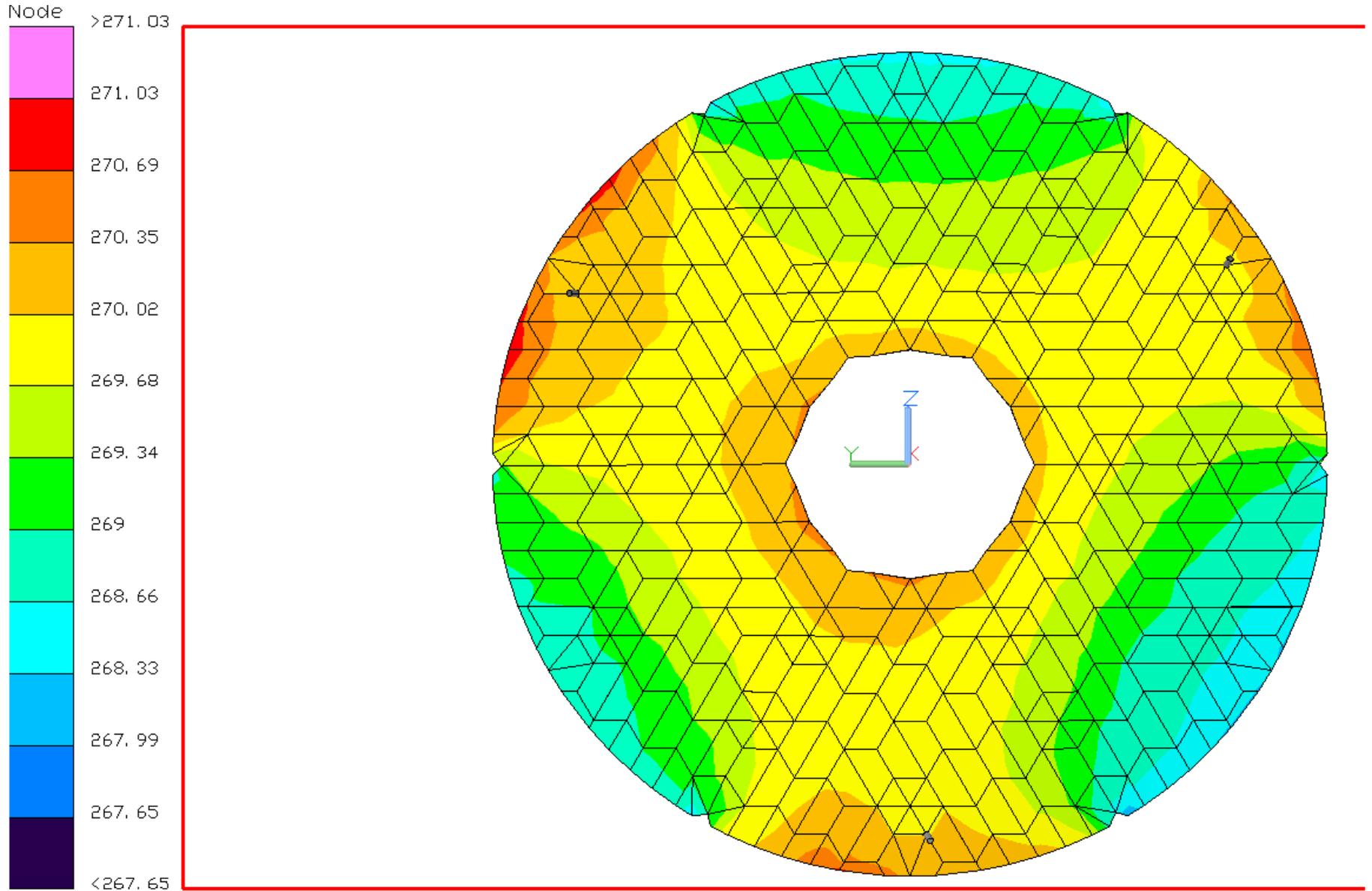
Orientation – sun at top
in these thermal plots



Temperature [K], Time = 252000 sec
D1V2_PID_117K_Integrated.sav

$\Delta T \sim 2K$

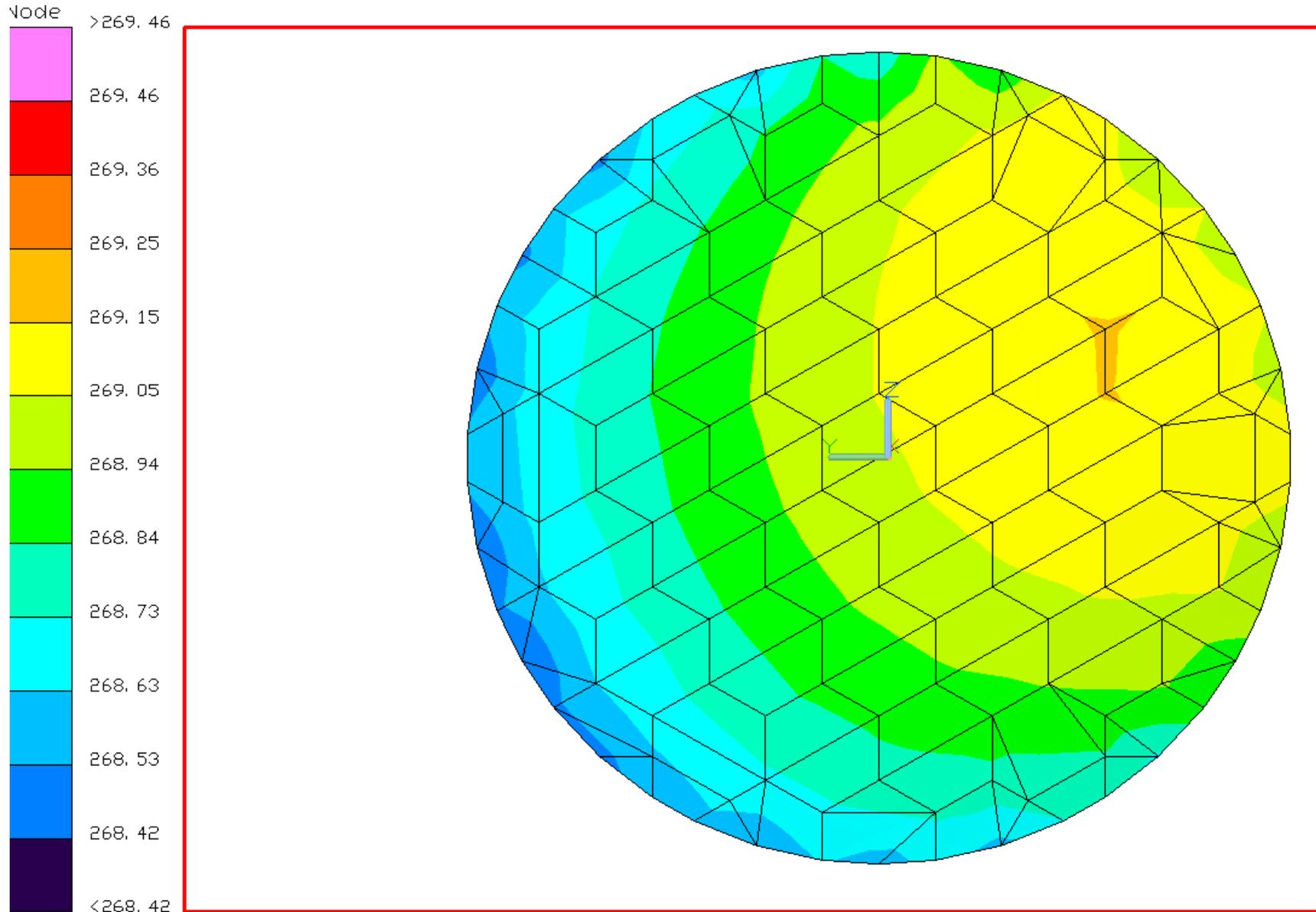
PM Back Orbital Hot Temp



Temperature [K], Time = 252000 sec
C1V2_PID_117K_Integrated.sav

$\Delta T \sim 2.5K$

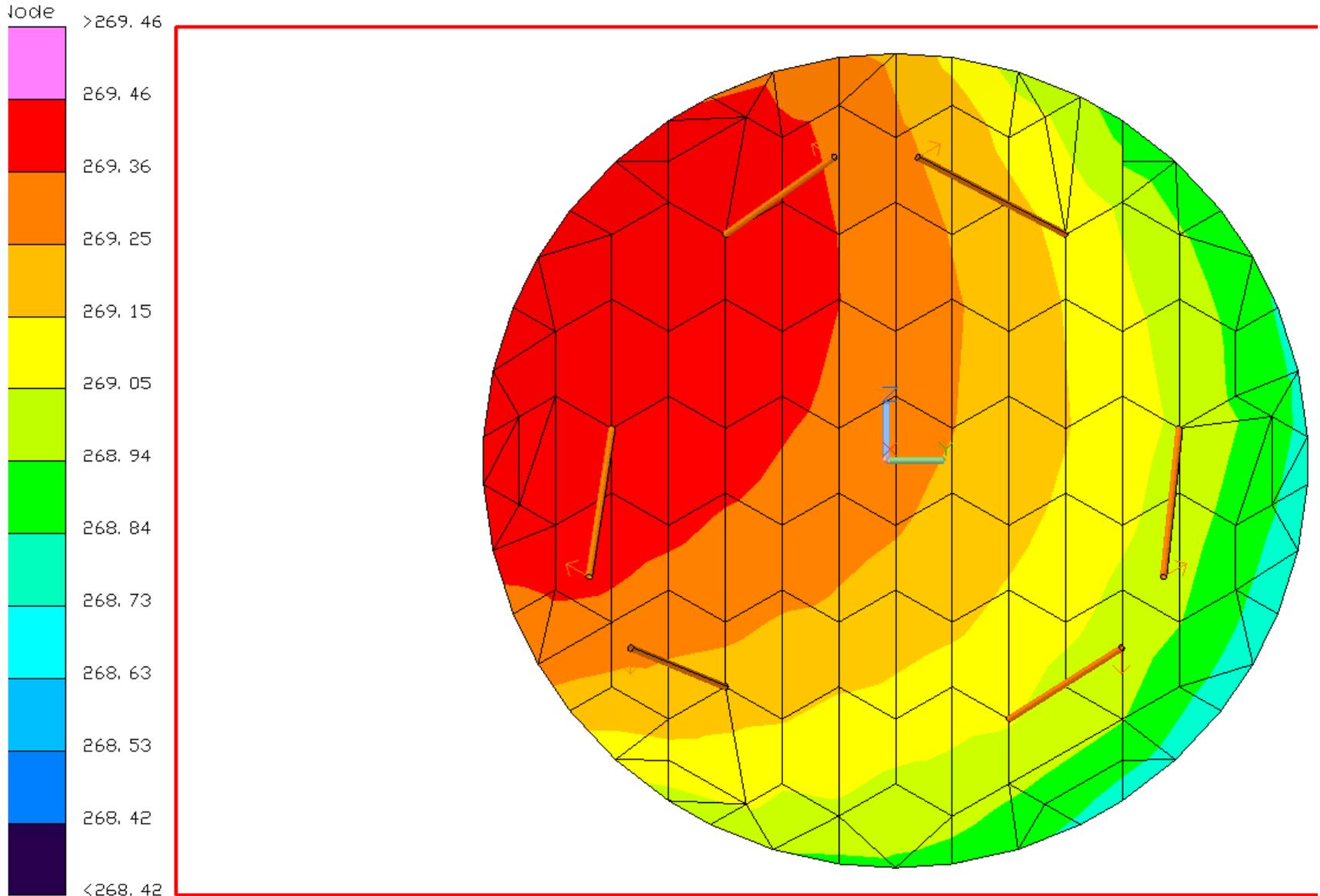
SM Front Orbital Hot Temp



Temperature [K], Time = 252000 sec
21V2 PID 117K Integrated.sav

$\Delta T \sim 0.7K$

SM Back Orbital Hot Temp



Temperature [K], Time = 252000 sec
1V2 PID 117K Integrated.sav

$\Delta T \sim 0.7K$

Cyc-3 Coronagraph-Useful Data Outputs

➤ From Nastran Structural/Thermal Distortion Runs:

- 24 hourly raw PM/SM shape changes for reference case orbit
- 24 hourly raw PM/SM 6-dof RB motions for reference case orbit
- 24 hourly raw Carrier CG latch point motions for reference case orbit

➤ From MatLab Post-Processing:

- 24 hourly PM/SM Zernikes 4-11 for reference case orbit
 - Could produce higher order Zernikes

T1, T2, and Carrier Stability Results <and> Δ WFE, Δ LOS, Δ PSF_ellip Results (latter for WF_Channel)

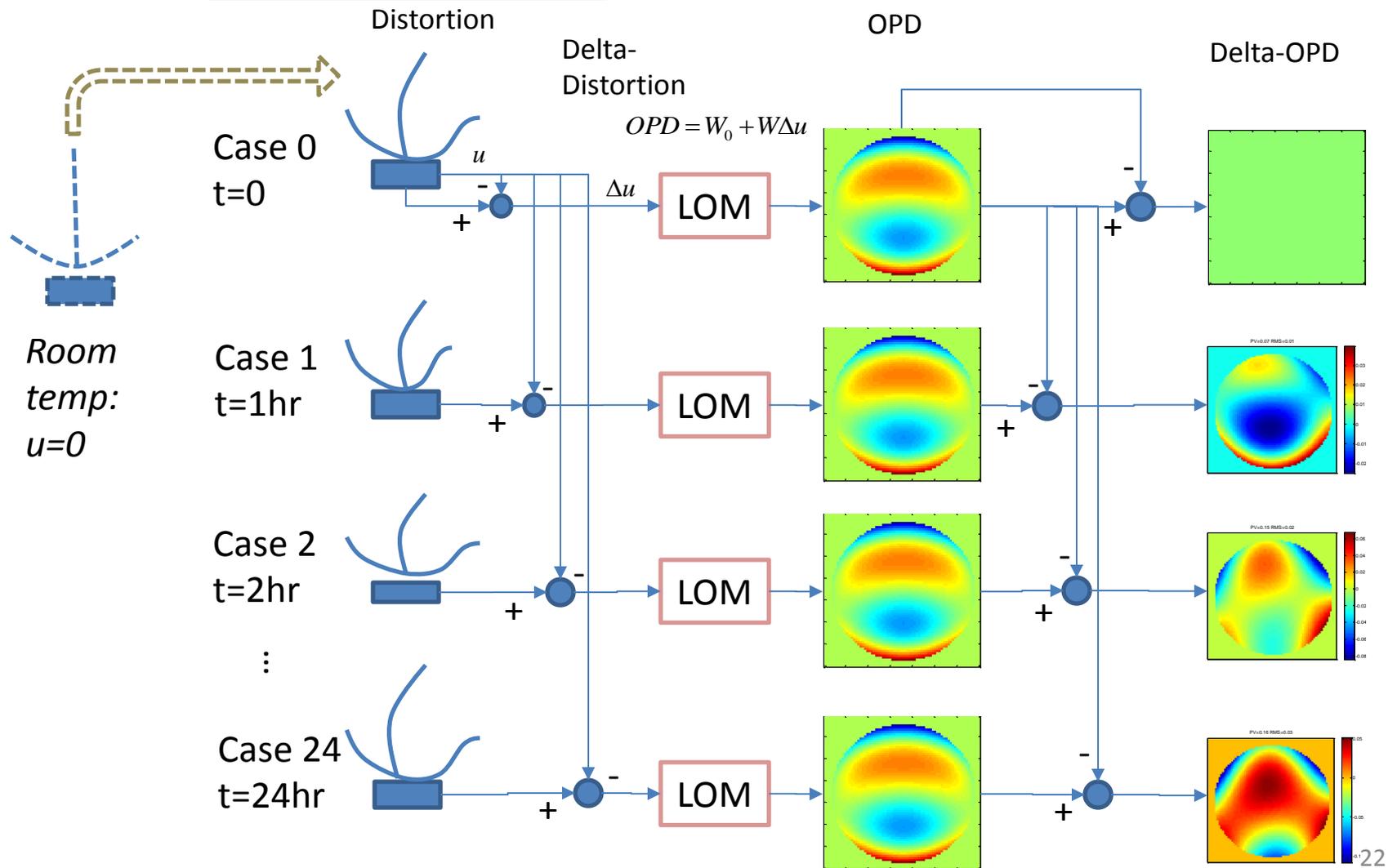
Carl Blaurock

9/25/2013

Delta-Distortion / Delta-WFE

Flow Overview

MUF=3.0 on distortion

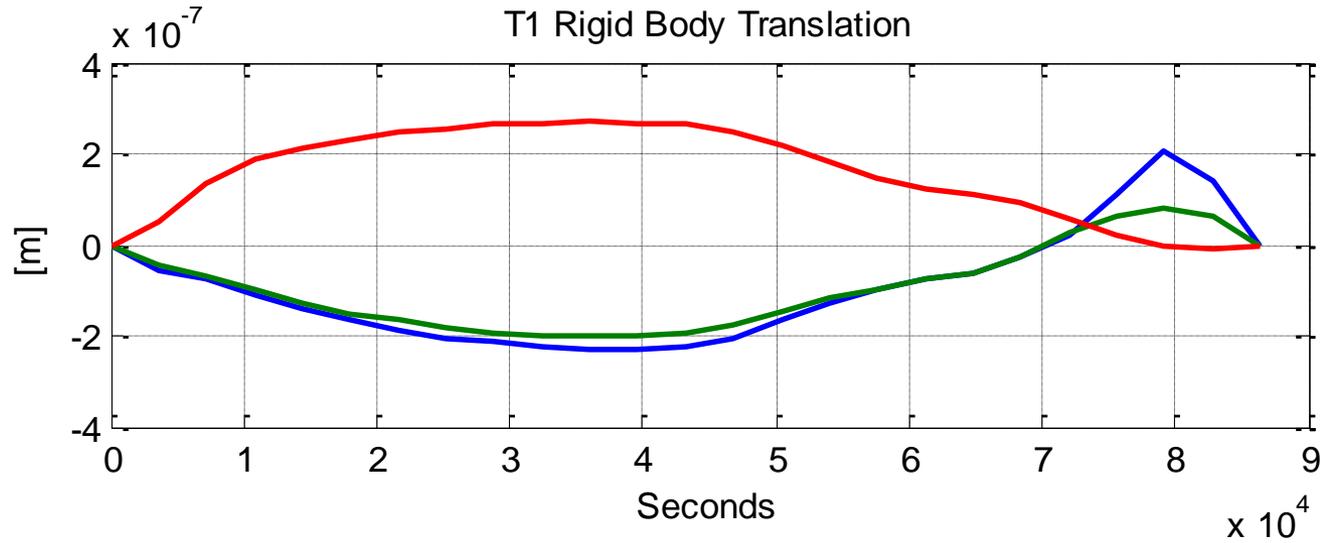


Sneak Peek at T1/T2 Rigid Body Motions and Deformations

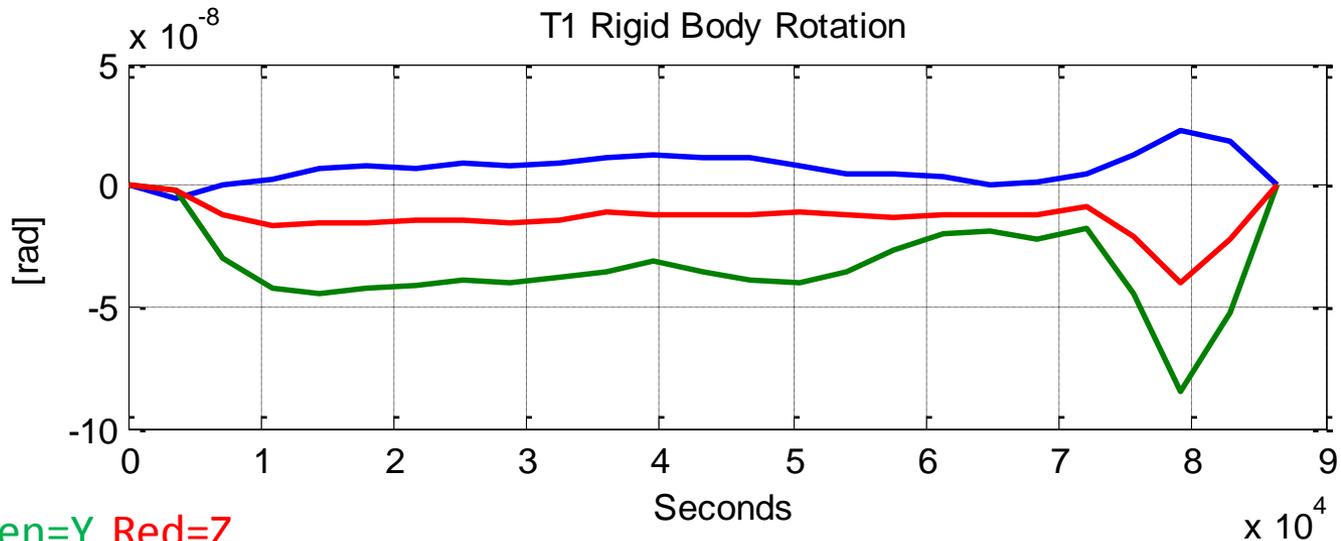
24 hourly time steps over one orbit (at equilibrium)

T1 Rigid Body Motions over 24 Hours

Meters
 $\times 10^{-7}$



Radians
 $\times 10^{-8}$

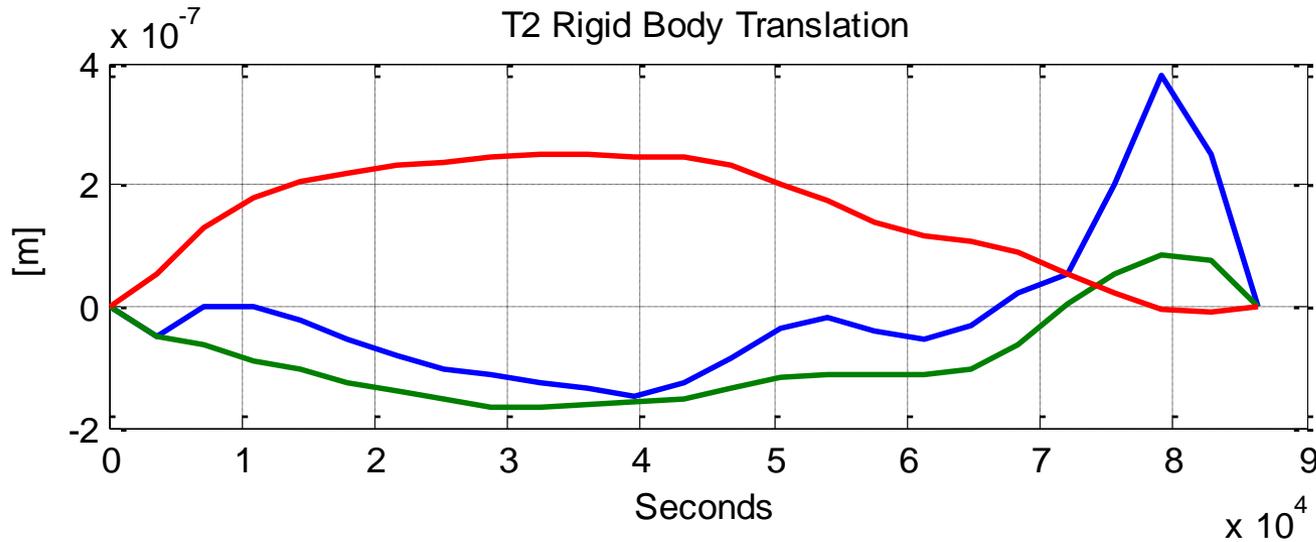


Blue=X, Green=Y, Red=Z

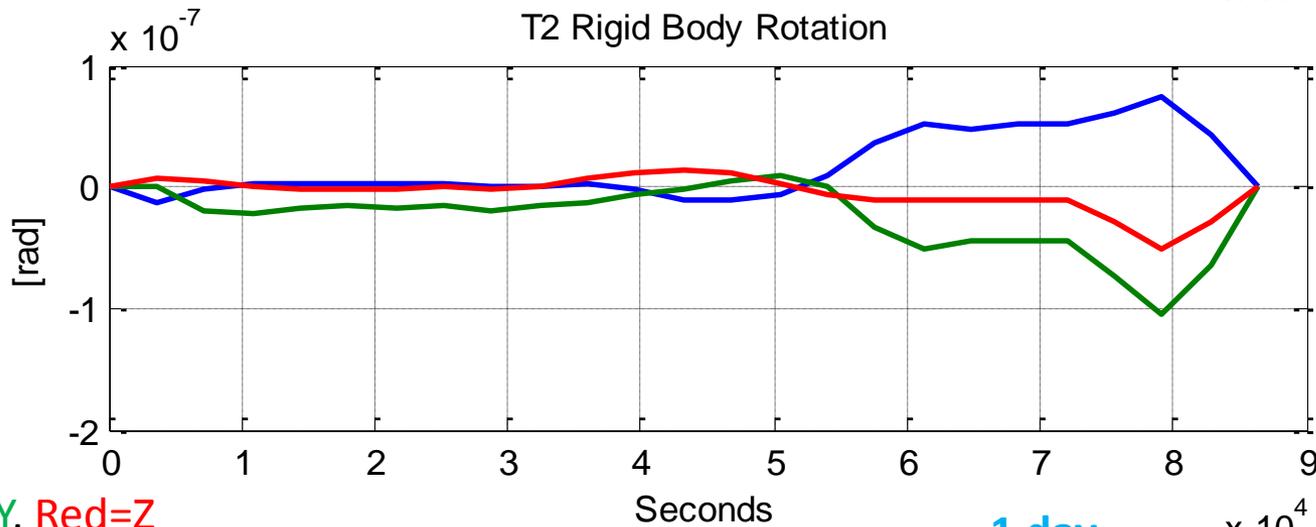
1 day

T2 Rigid Body Motions over 24 Hours

Meters
 $\times 10^{-7}$



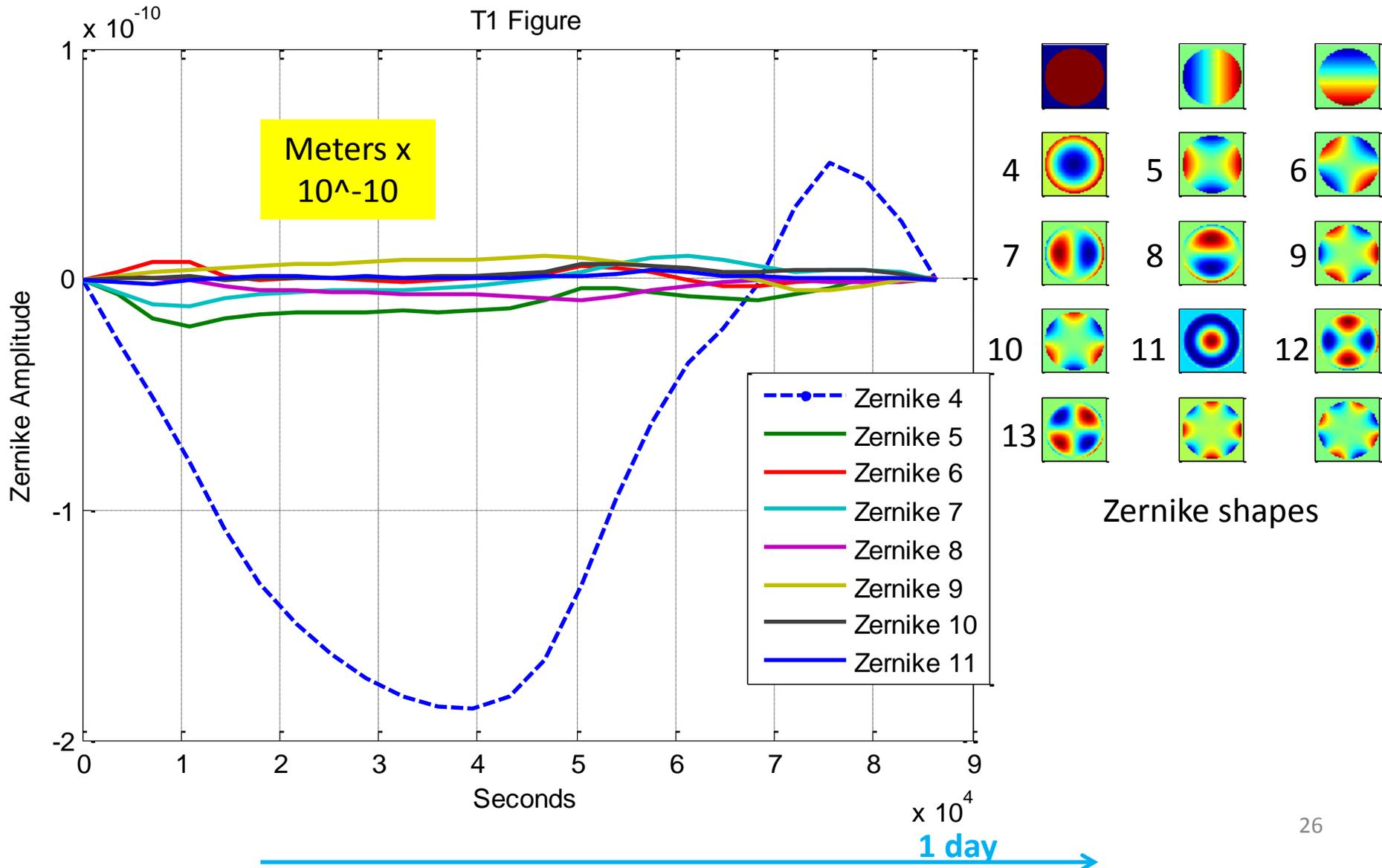
Radians
 $\times 10^{-7}$



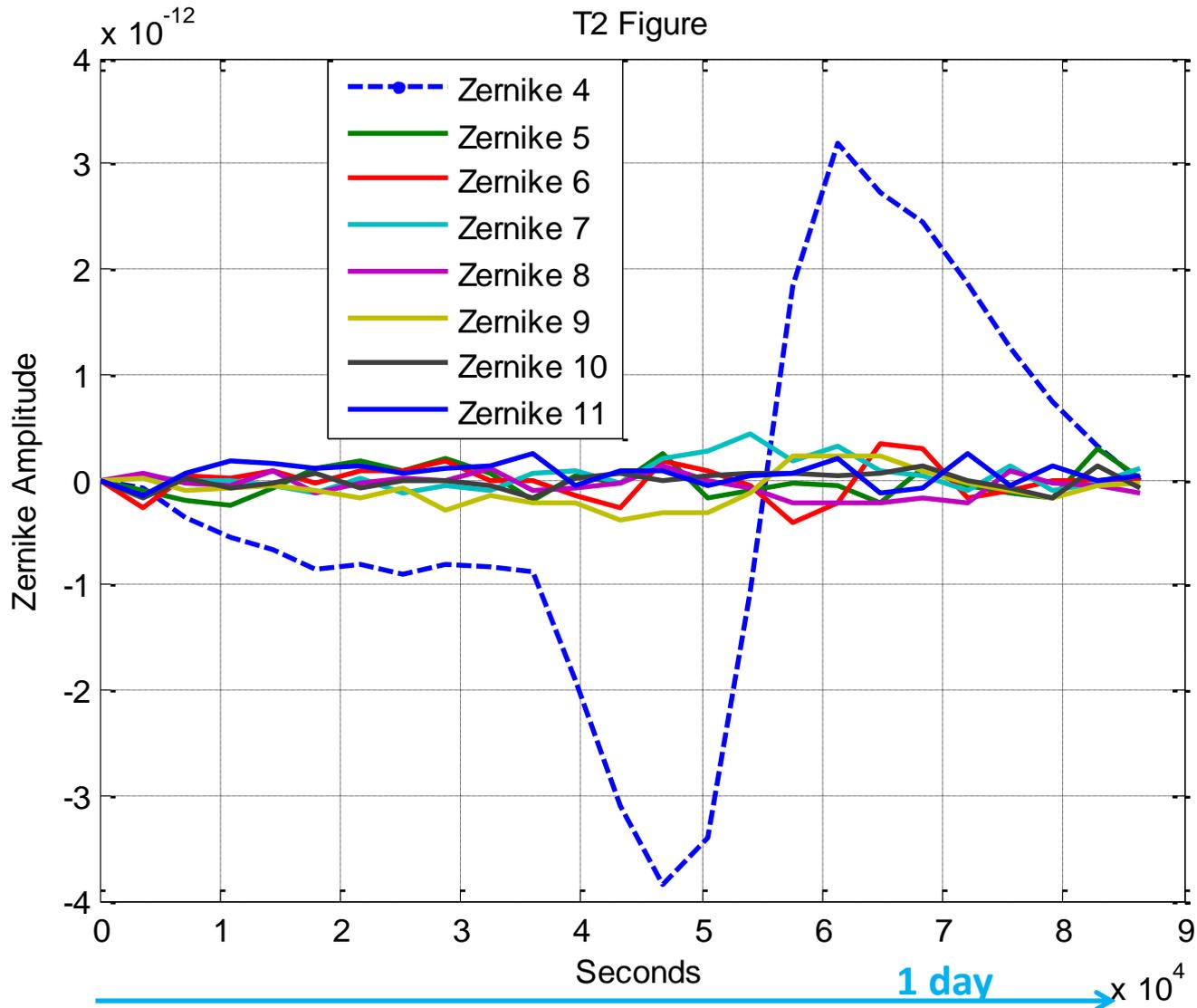
Blue=X, Green=Y, Red=Z

1 day

T1 Zernike Amplitudes over 24 Hours



T2 Zernike Amplitudes over 24 Hours

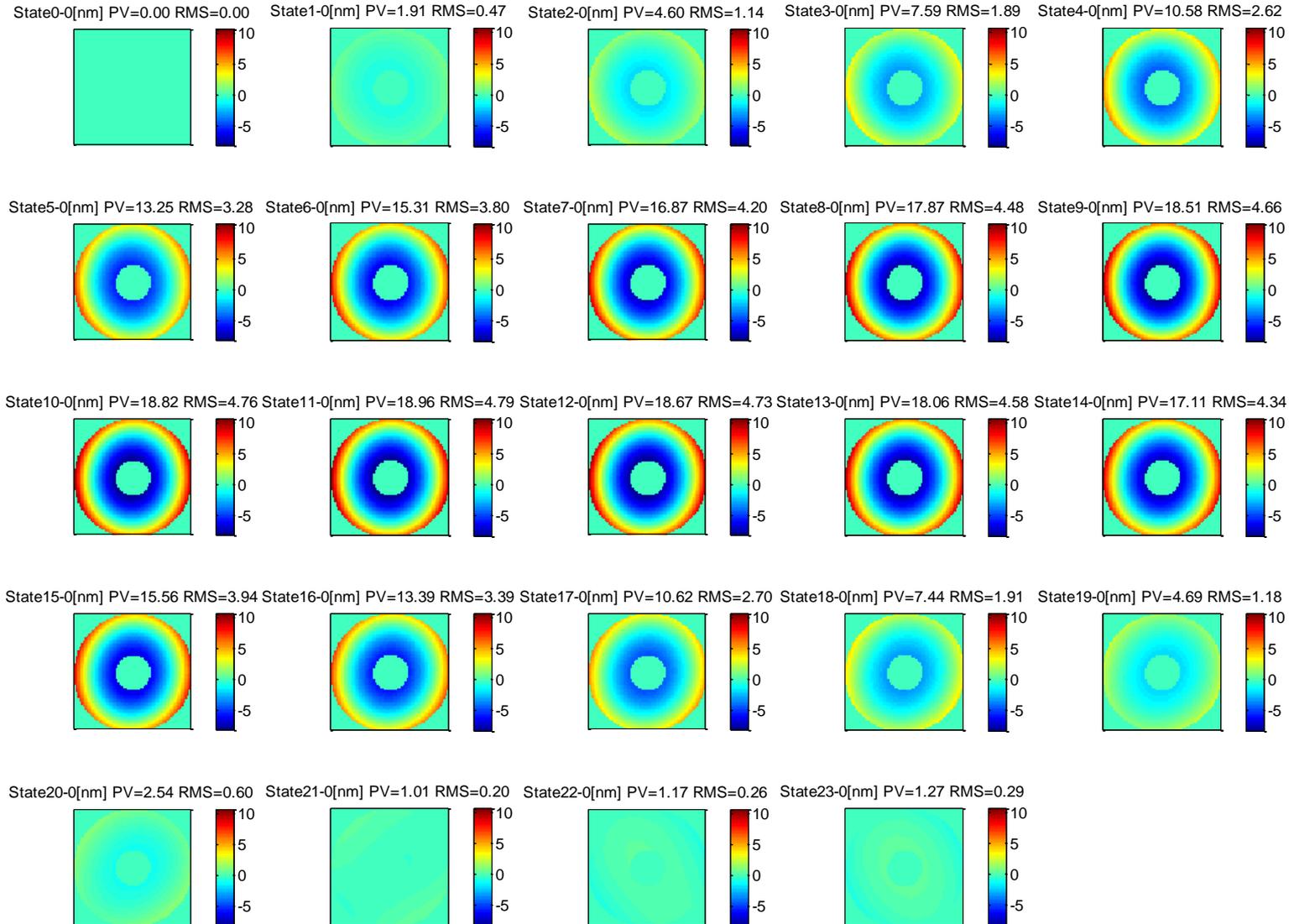


Meters x 10^{-12}

ΔWFE , ΔLOS , ΔPSF_ellip Results for WF_Channel

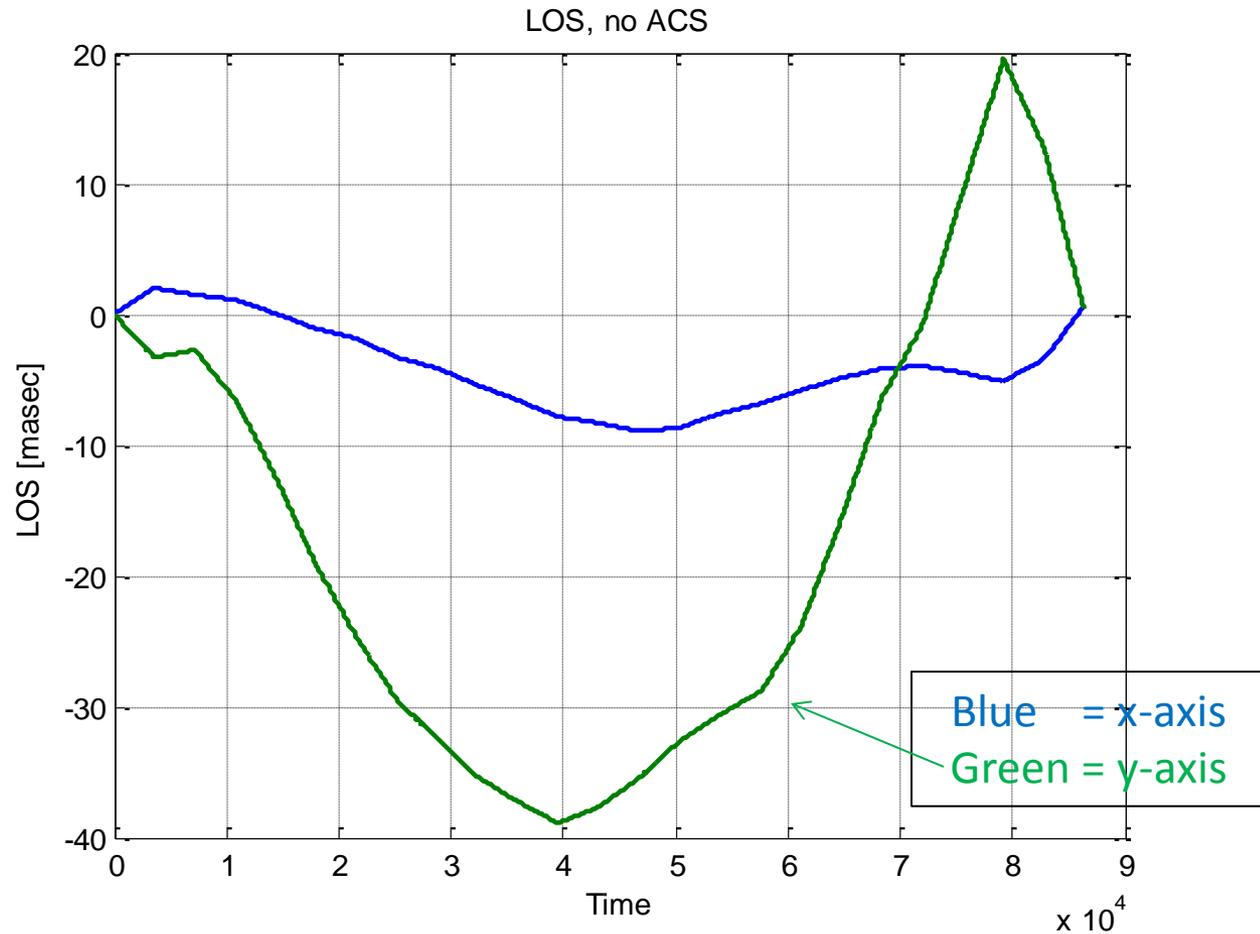
24 hourly time steps over one orbit (at equilibrium)

Delta-OPD Maps (Delta-Distortion)



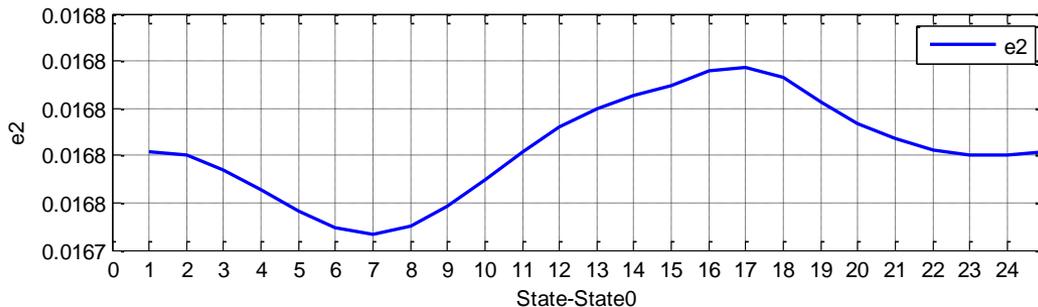
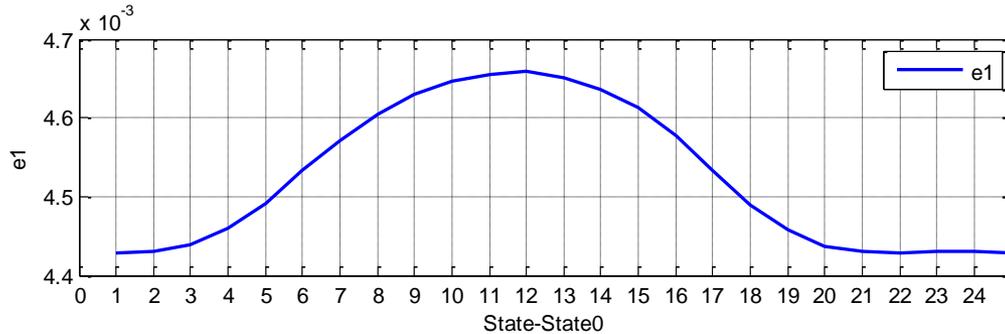
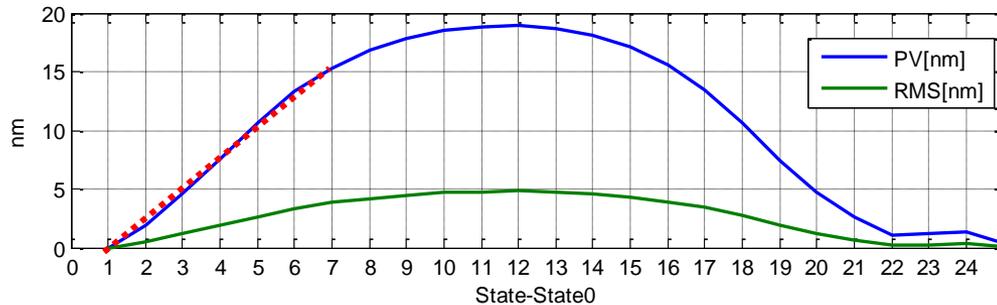
Peak is ~5nm after 11 hours; easily meets the 1nm/184 sec WFI requirements

Thermo-elastically induced Line of Sight (LOS) Motion Over 1 Day



Very small compared to jitter observatory requirement of 20 masec rms/axis

Ellipticity Summary

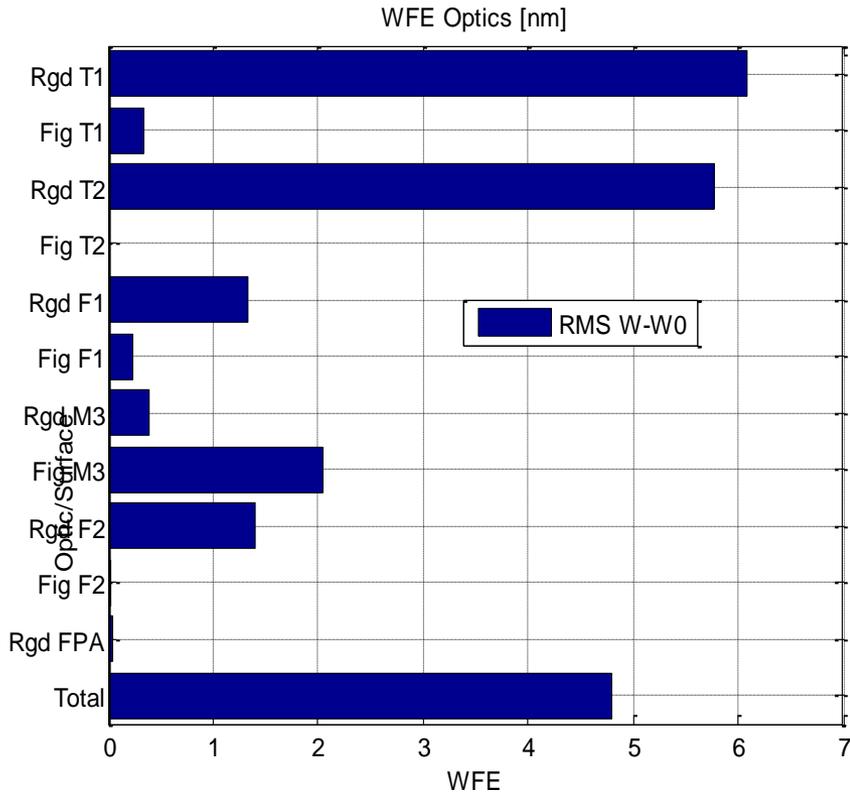


Ellipticity details in backup p.56

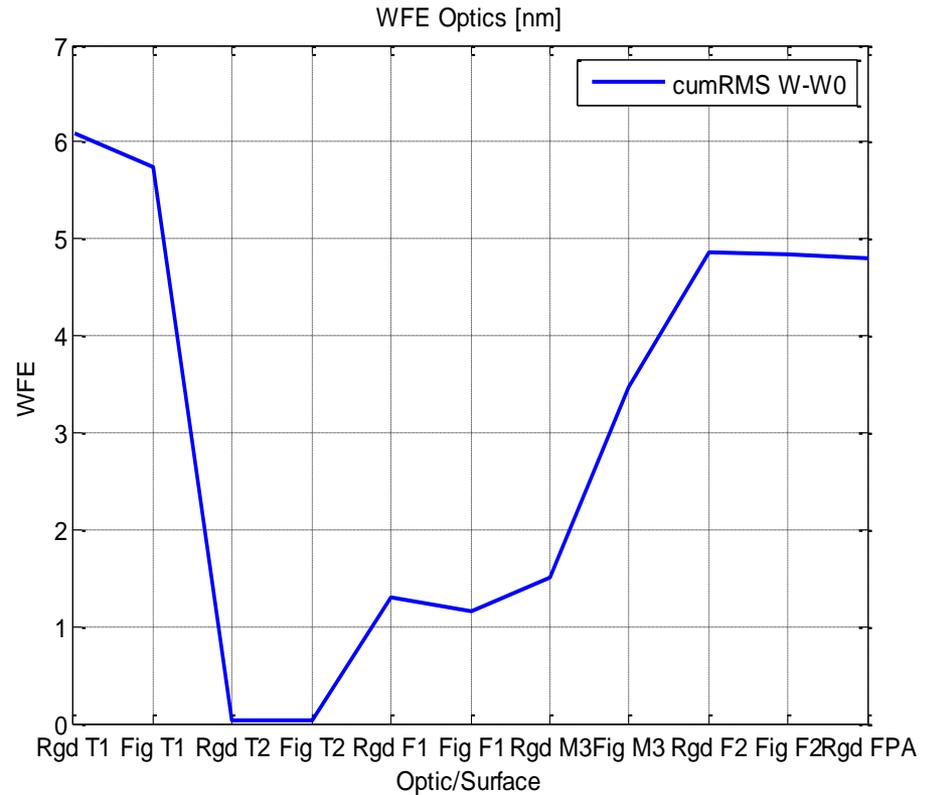
State	PV [nm]	RMS [nm]	e1	e2
State0	0.0	0.0	0.004429	0.016782
State1	1.9	0.5	0.004431	0.016780
State2	4.6	1.1	0.004439	0.016774
State3	7.6	1.9	0.004459	0.016765
State4	10.6	2.6	0.004492	0.016757
State5	13.2	3.3	0.004532	0.016750
State6	15.3	3.8	0.004571	0.016747
State7	16.9	4.2	0.004605	0.016750
State8	17.9	4.5	0.004630	0.016758
State9	18.5	4.7	0.004647	0.016770
State10	18.8	4.8	0.004655	0.016781
State11	19.0	4.8	0.004658	0.016792
State12	18.7	4.7	0.004650	0.016800
State13	18.1	4.6	0.004636	0.016806
State14	17.1	4.3	0.004613	0.016810
State15	15.6	3.9	0.004578	0.016816
State16	13.4	3.4	0.004533	0.016818
State17	10.6	2.7	0.004490	0.016813
State18	7.4	1.9	0.004457	0.016803
State19	4.7	1.2	0.004437	0.016793
State20	2.5	0.6	0.004430	0.016787
State21	1.0	0.2	0.004429	0.016783
State22	1.2	0.3	0.004430	0.016780
State23	1.3	0.3	0.004430	0.016780
State24	0.4	0.1	0.004429	0.016782

Peak is $\sim 5\text{nm}$ Δw_{fe} , ~ 0.00023 e1 after 11 hours; easily meets the 1nm/184 sec, $1.e-4$ $\Delta e/184$ sec WFI requirements; red line shows 15 nm/6 hours = 2.5nm/hour but almost all focus which ought to be taken out by LOWFS

State 11 RMS Δ WFE by Optic



RMS WFE for each optic; Total is sum of all the optics. T1 and T2 have large individual contributions but they partially cancel.

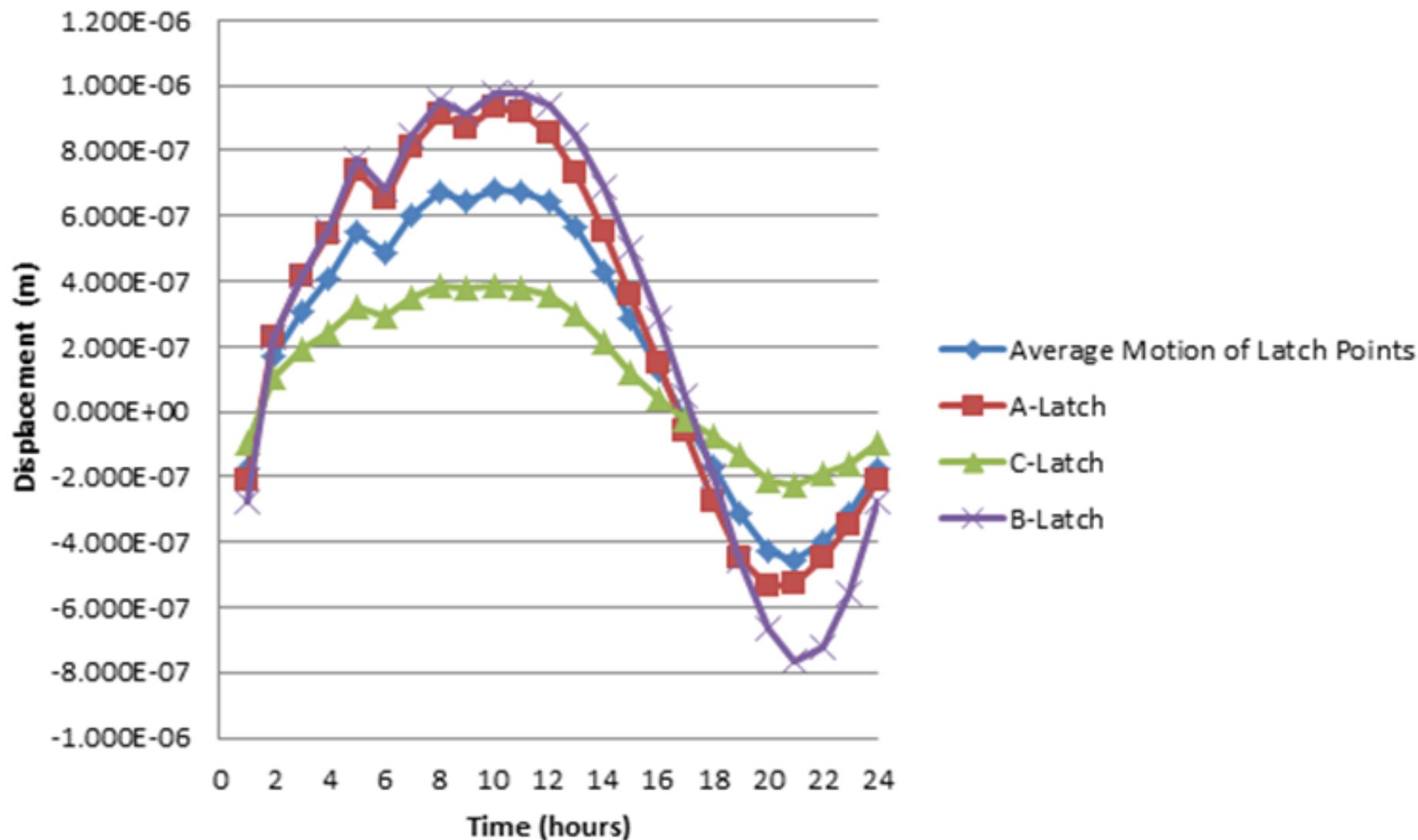


Cumulative RMS by optic; sum of the OPD maps from the optic plus all upstream optics.

Carrier CG Latch Interface Motions

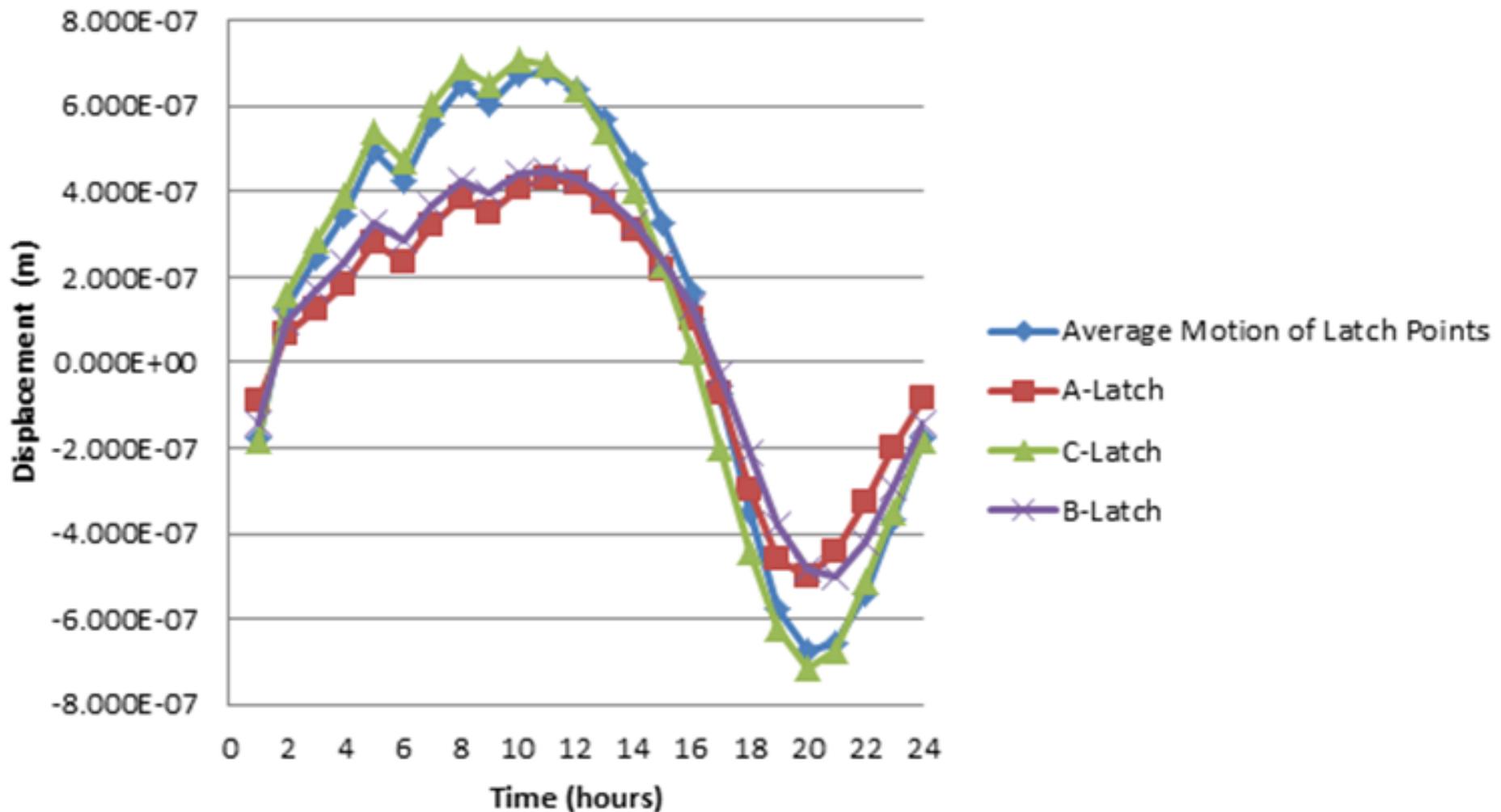
- These results are preliminary, and are shown to provide a first look at Cyc-3 Instrument Carrier mechanical stability;
- The Cyc-3 design does not incorporate any thermal control on the Carrier, which could be added in the future;
- These results are in the WFI coordinate system. Future results will be output in a coordinate system which is orthogonal to the coronagraph's latch DOF axis. We would prefer to report motions in a coordinate system that is set up for the coronagraph only, similar to the WFI (i.e. x axis would be along the extraction axis of coronagraph, Z would be launch axis);
- Some of these motions will be modified by the DOF of the kinematic mount latches but we can't show that in the current coordinate system.

Orbital Stability of Coronagraph Latch Locations. MUF = 3.0. Total Translations.



Orbital Stability of Coronagraph Latch Locations.

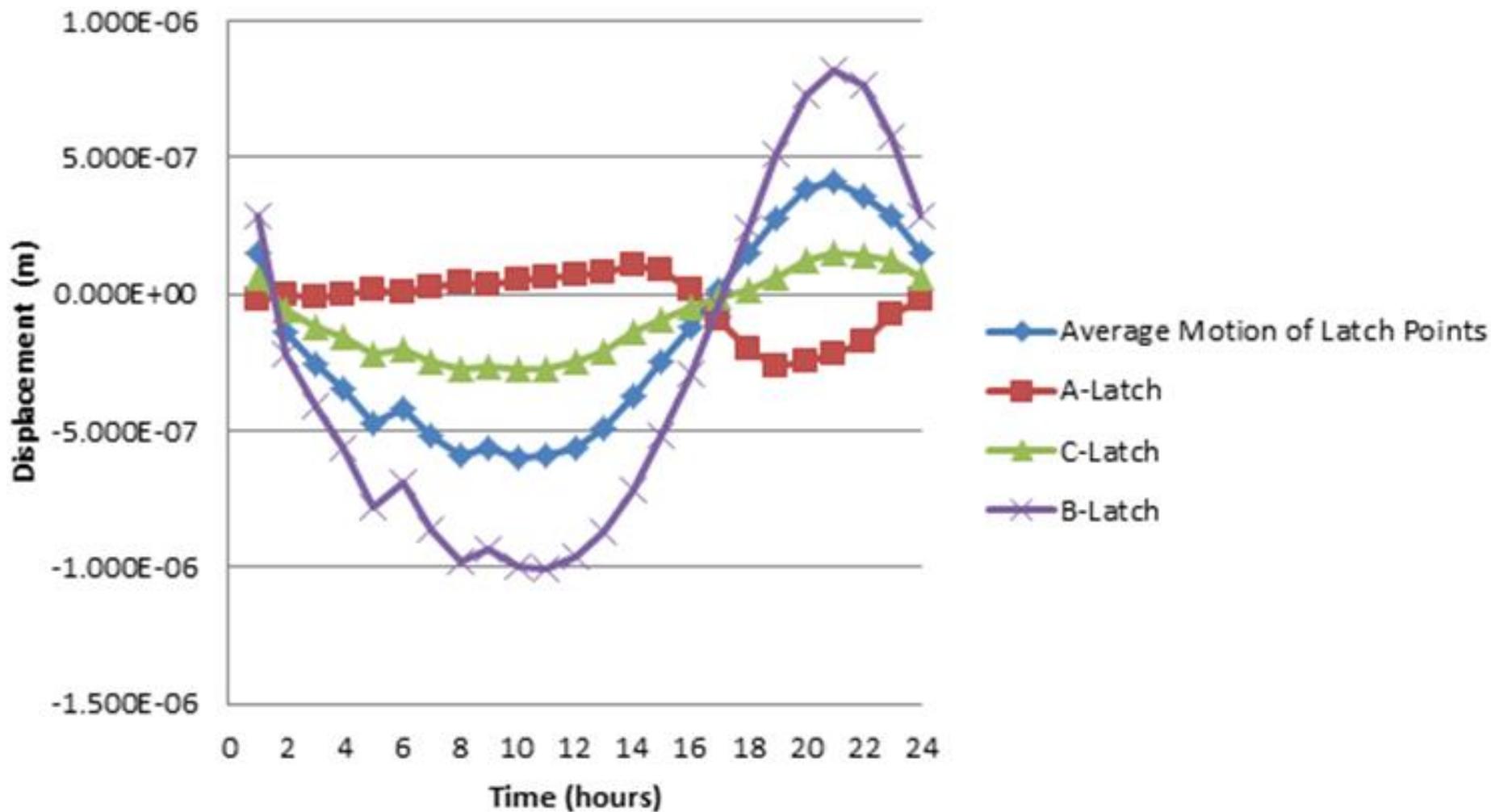
MUF = 3.0.
X Translations.



Orbital Stability of Coronagraph Latch Locations.

MUF = 3.0.

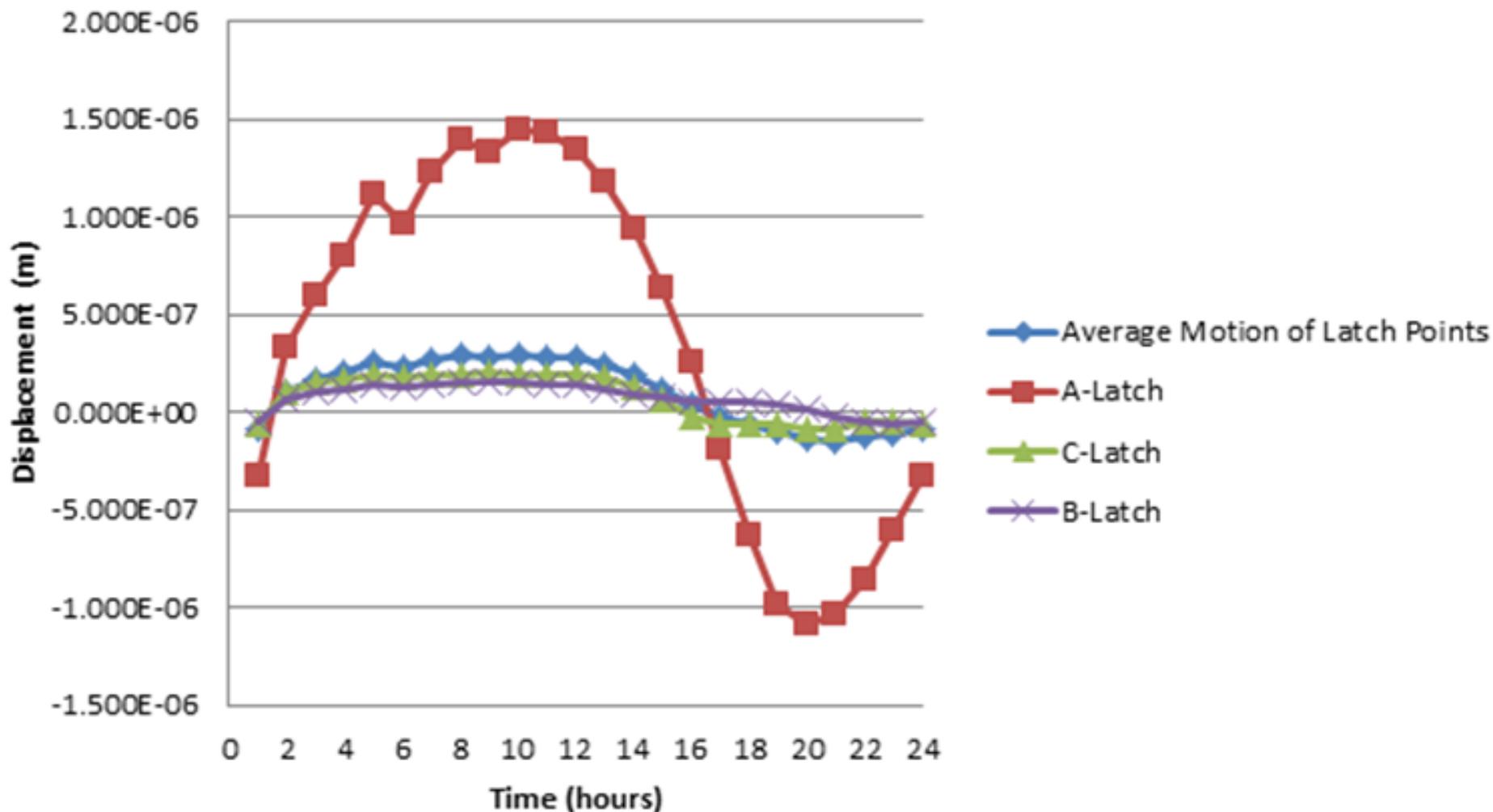
Y Translations.



Orbital Stability of Coronagraph Latch Locations.

MUF = 3.0.

Z Translations.



Caveat

- Caveat – 1st IM case we have looked at in the inclined GEO orbit
 - Chosen to isolate the thermal disturbances to orbital Earth input variations only ... how bad are GEO disturbances alone?
 - Fixed attitude w/pitch/roll = 0; azimuth choice maximizes Earth input variation into telescope aperture (and close for WFI radiator);
 - Equilibrium case shown, with not even 1°/day solar motion;
 - Plan to thermally triage pitch/roll extremes w/azimuth chosen to maximize Earth disturbances;
 - If no surprises, pick an attitude, generate equilibrium thermal profile, and use it as initial condition for a thermally different attitude and track the thermal settling over several orbits for use in an IM assessment.

Take-Aways, Future Cyc-3 Work and Issues

➤ Take-Aways

- It does appear that time scales are no faster than diurnal, which “should be” amenable for LOWFS to compensate

➤ Future Cyc-3 Work

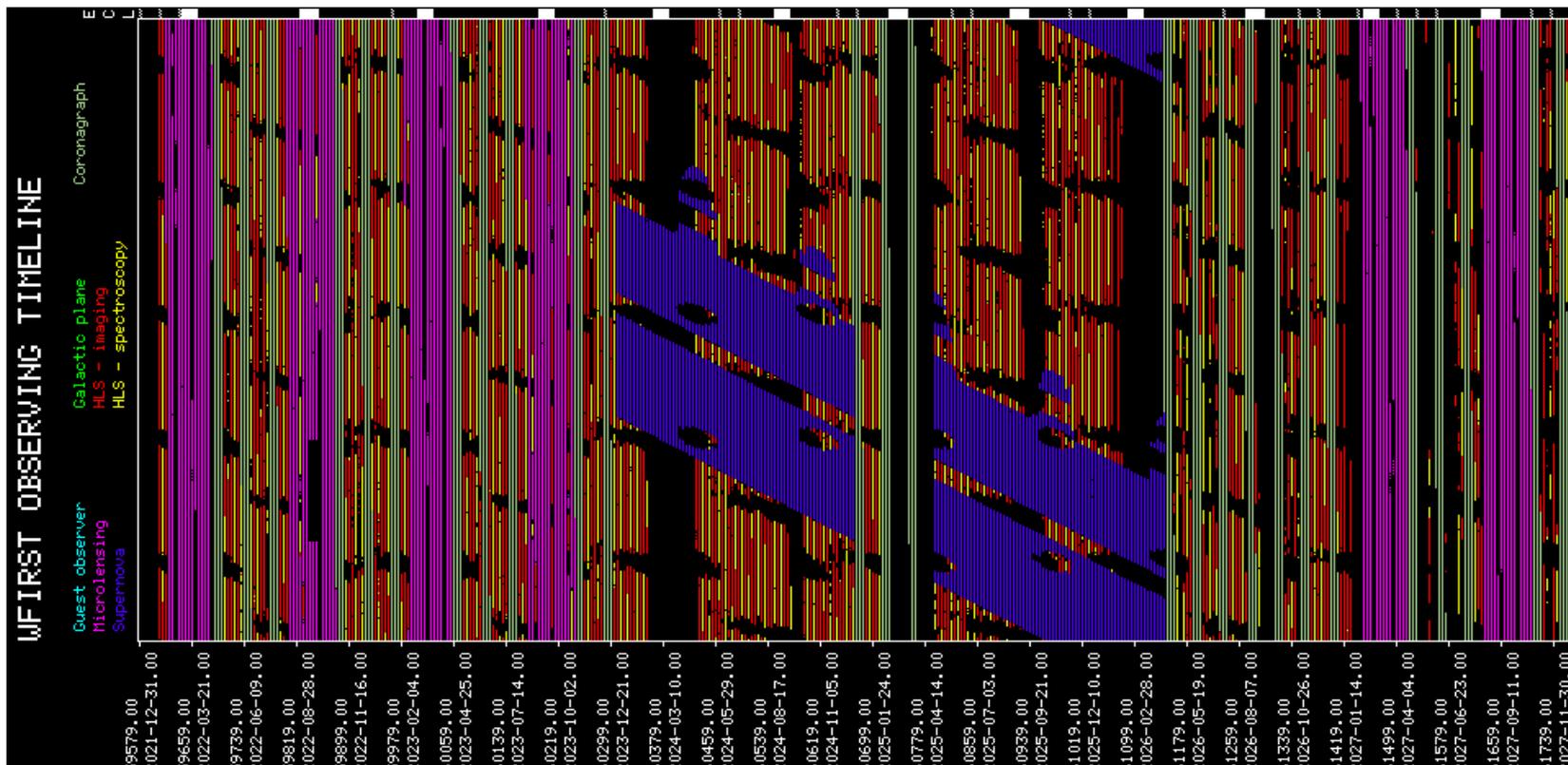
- Cyc-3 Jitter
- Cyc-3 Cooldown
- Cyc-3 1g
- High Latitude Survey realistic 5-day slewing case

➤ We will be doing Cycle4 design and STOP analysis starting late CY13

➤ Issues

Existence proof Observing sequence [w/ coronagraph]

p.83 of April final report: These observations are scheduled in 26 blocks of 2 weeks each, interspersed throughout the mission.



The example WFIRST-2.4 observing sequence [w/ coronagraph]. Each column indicates a 5-day interval, with the programs color-coded. The row at top shows Earth eclipse seasons (solid rectangles) and passages through the lunar penumbra (vertical lines). The microlensing seasons (magenta) are visible with the lunar cutouts removed. The supernova program (blue) is spread over 2 years: observations are scheduled every 5 days, but are broken into chunks due to Earth viewing and radiator angle cutouts. The HLS fills in much of the remaining time. Note that Earth eclipse seasons occur during the microlensing campaigns. Unallocated time is shown in black: it is anticipated that this will be devoted to the GO program. The green blocks indicate the coronagraph observing periods.

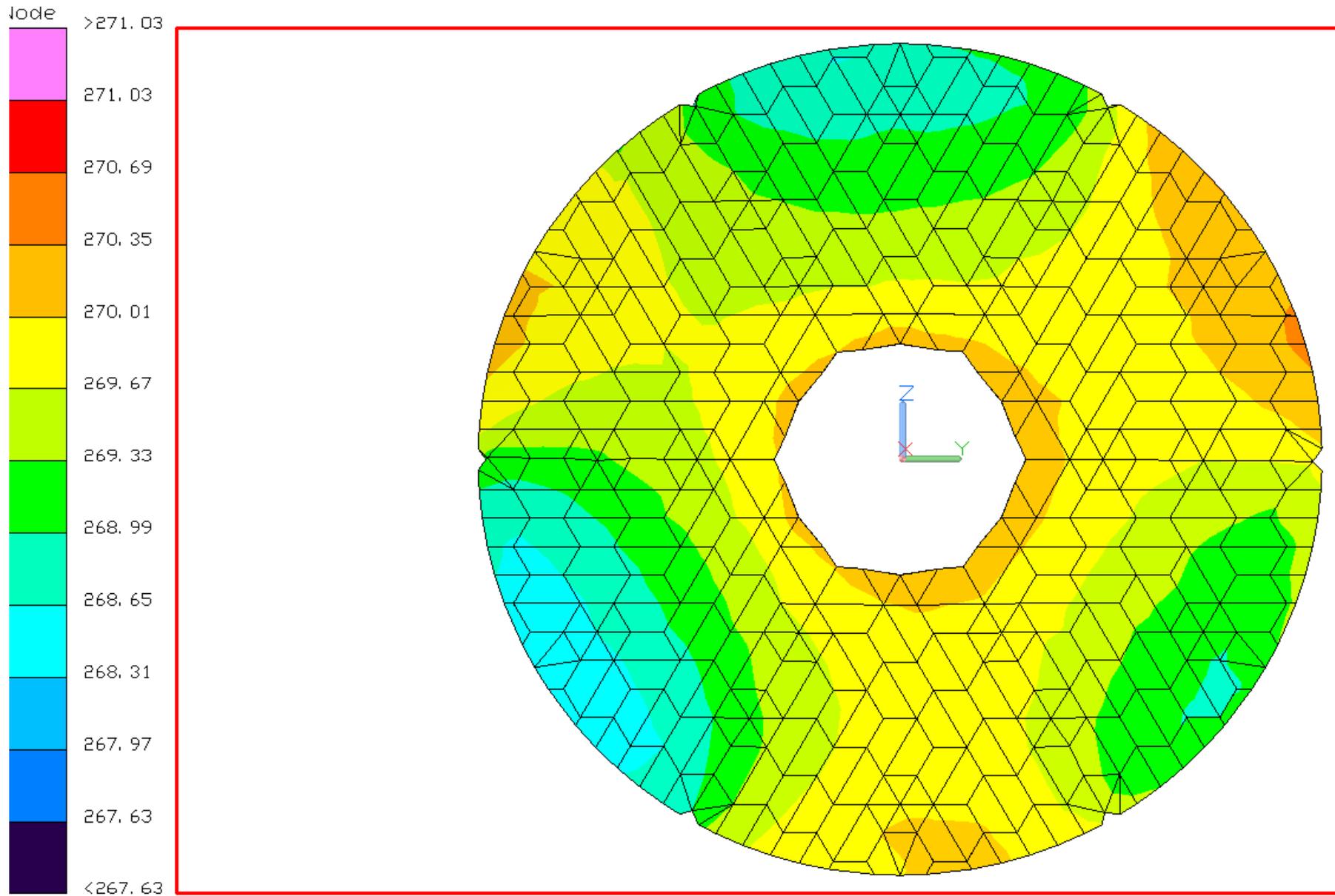
Backup

Simplified Integrated Modeling Breakout (2 of 2)

➤ SVOP (Structural/Vibration Optical Performance) Analysis

- Generate a Linear Optical Model (LOM), using Code-V to perturb each optical element in 6-dof RB motions, and relate the size of the motion to the delta WFE and LOS resulting at the WF_channel exit pupil. This is the same LOM used in the STOP analysis but note that no deformations of the optics are included;
- Apply vibration sources to a Nastran dynamics model which includes structural representations of ideal optical element surfaces/shapes in their ideal positions (as modeled in Code-V);
- RBE3 RB motions of the optical elements are output in the local optical element coordinate system ... none of the optical elements are deformed;
- The LOM is multiplied by the optical element RB motions predicted in response to the given vibration input, and the result is a time-history predict of the change in WFE/LOS induced by the disturbance;
- Separate MatLab post processing is used to produce a time history predict of the change in PSF ellipticity produced by the disturbance.

PM Front Orbital Cold Temp

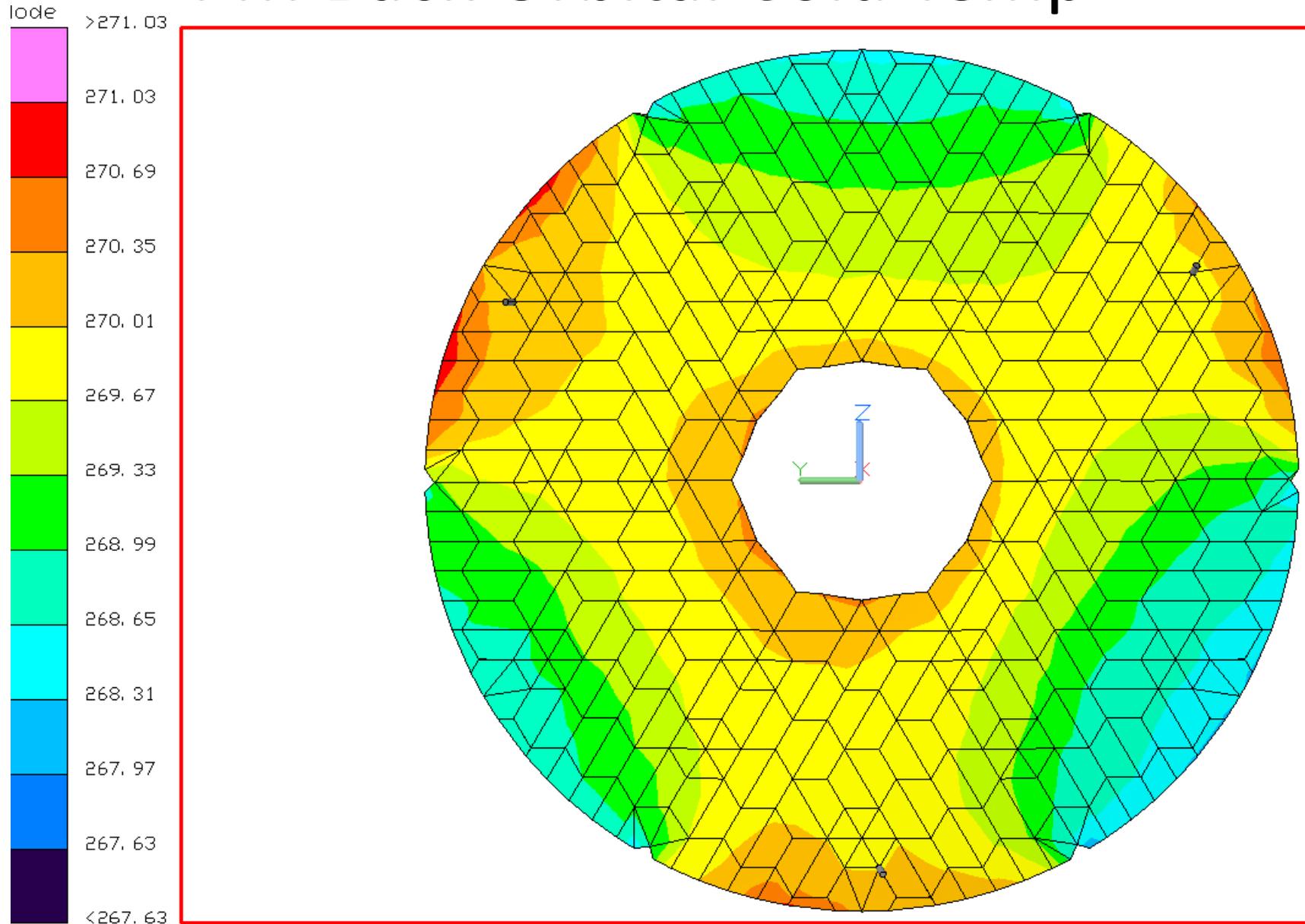


Temperature [K], Time = 298800 sec

1V2 PID 117K Integrated.sav

$\Delta T \sim 0.7\text{K}$

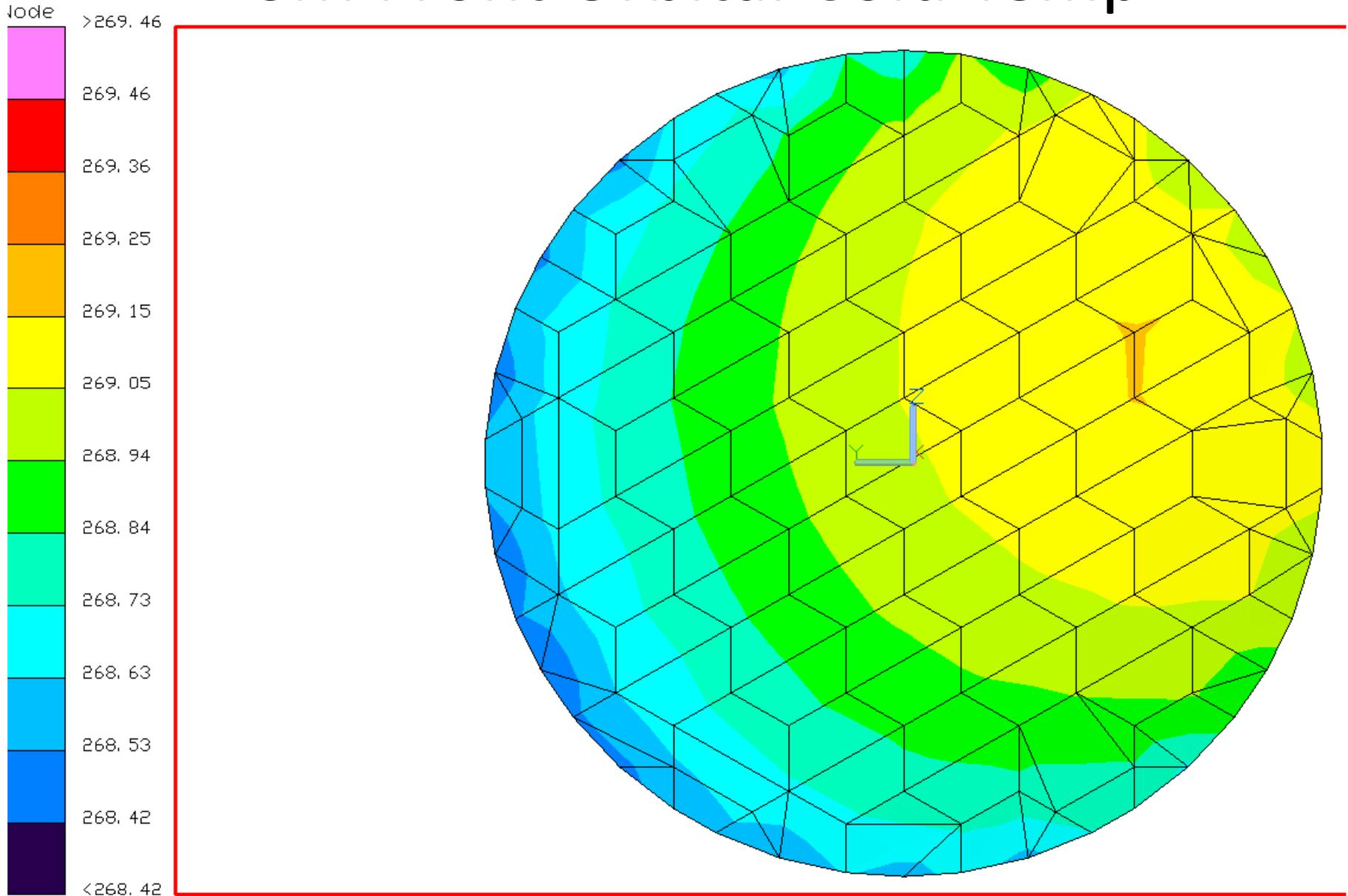
PM Back Orbital Cold Temp



temperature [K], Time = 298800 sec
:1V2 PID 117K Integrated.sav

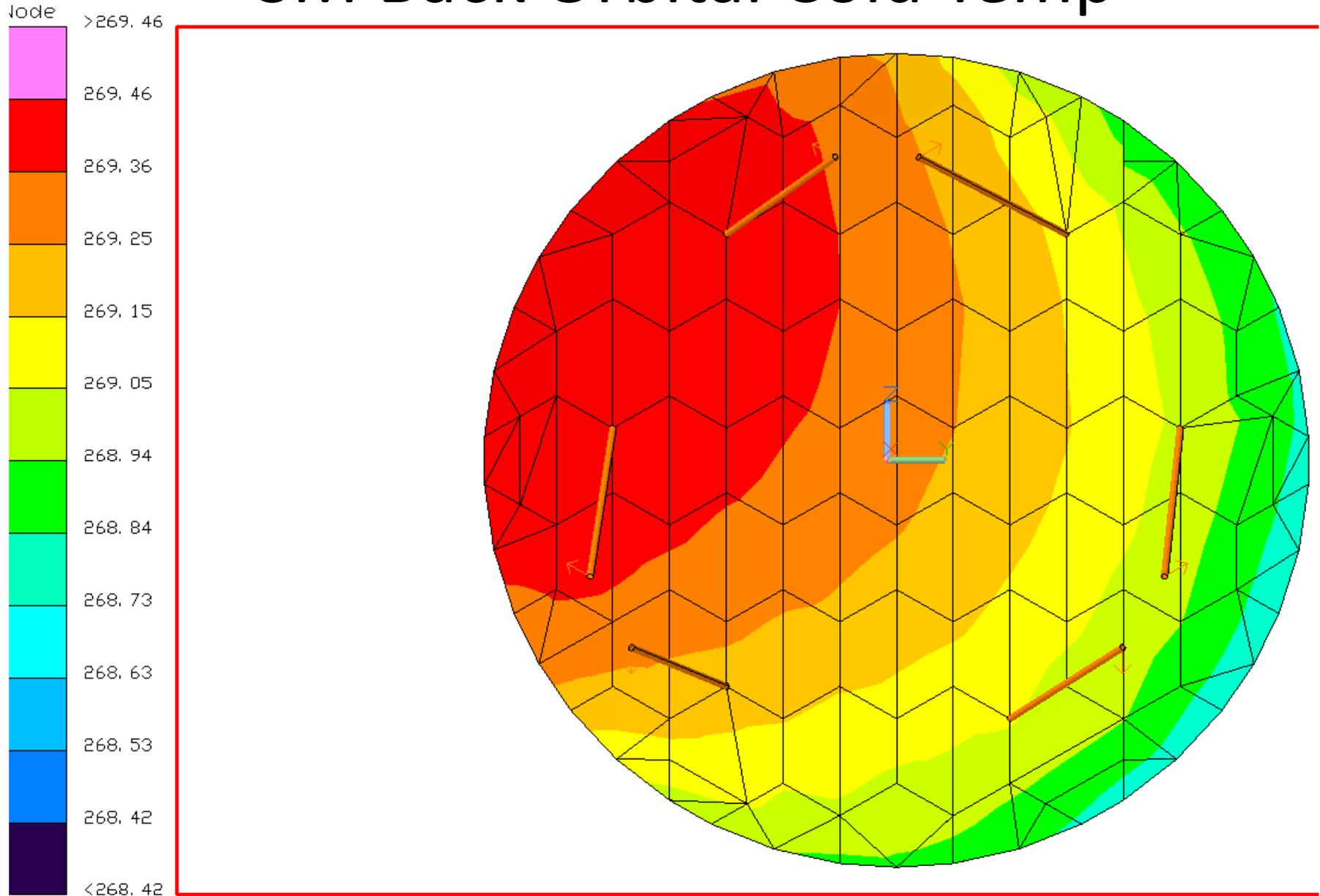
$\Delta T \sim 1.4\text{ K}$

SM Front Orbital Cold Temp



$\Delta T \sim 0.9\text{K}$

SM Back Orbital Cold Temp

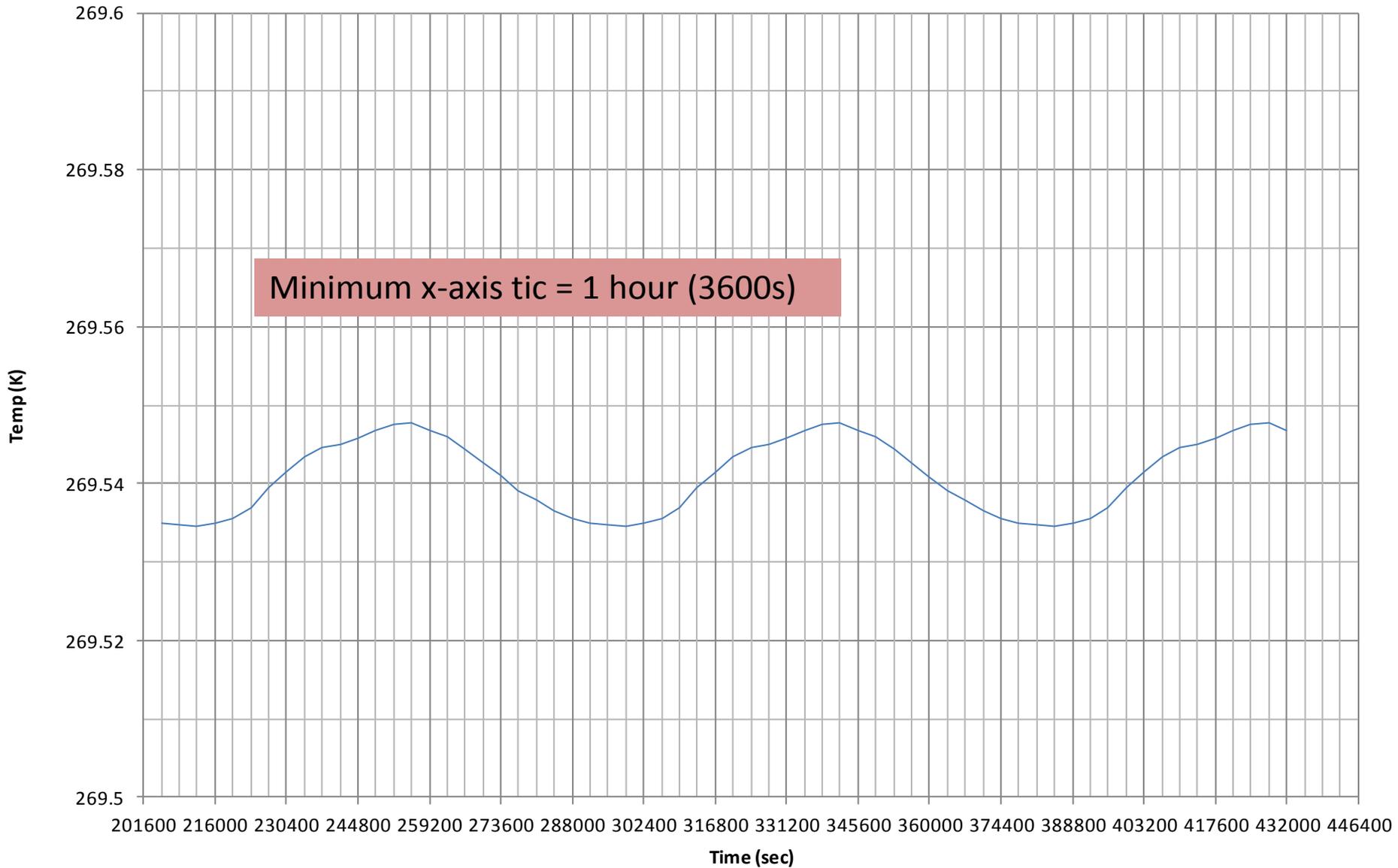


Temperature [K], Time = 298800 sec
1V2 PID 117K Integrated.sav

$\Delta T \sim 0.7K$

WFIRST Primary Mirror - Front

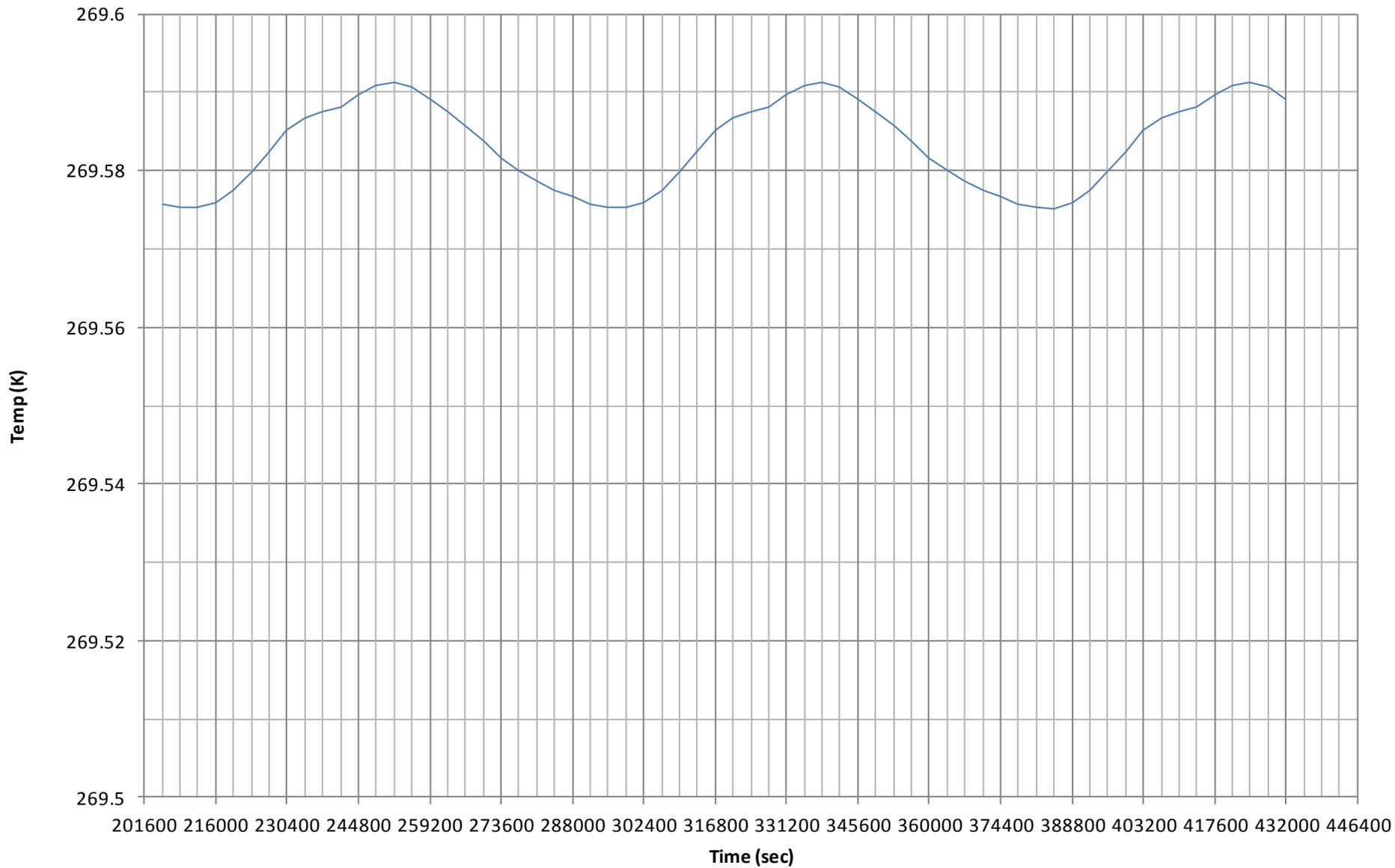
C1V2:PM_Front



N.B. Later PM/SM Hot Pics at T=252000, Cold Pics at T=298800

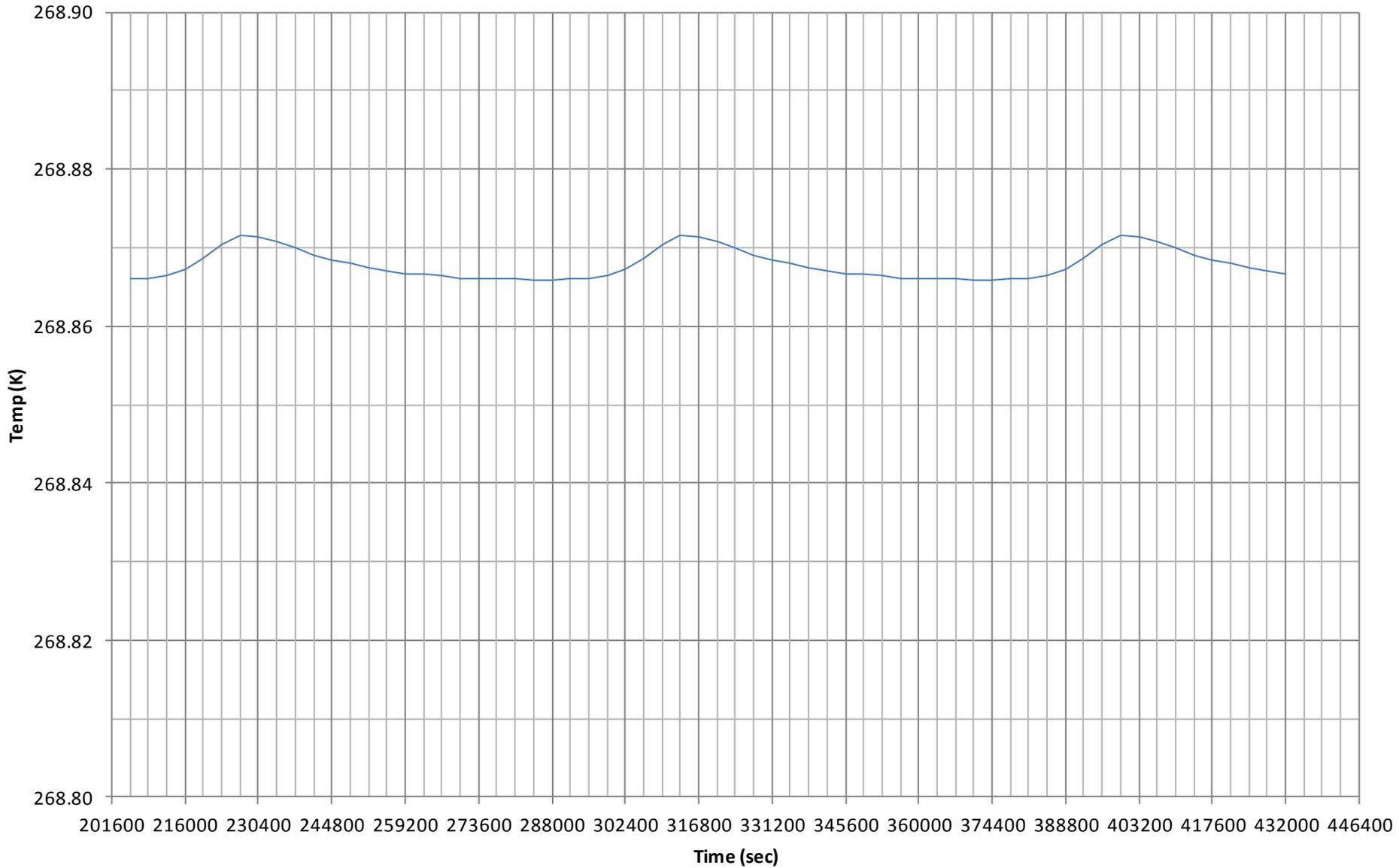
WFIRST Primary Mirror - Back

C1V2:PM_Back



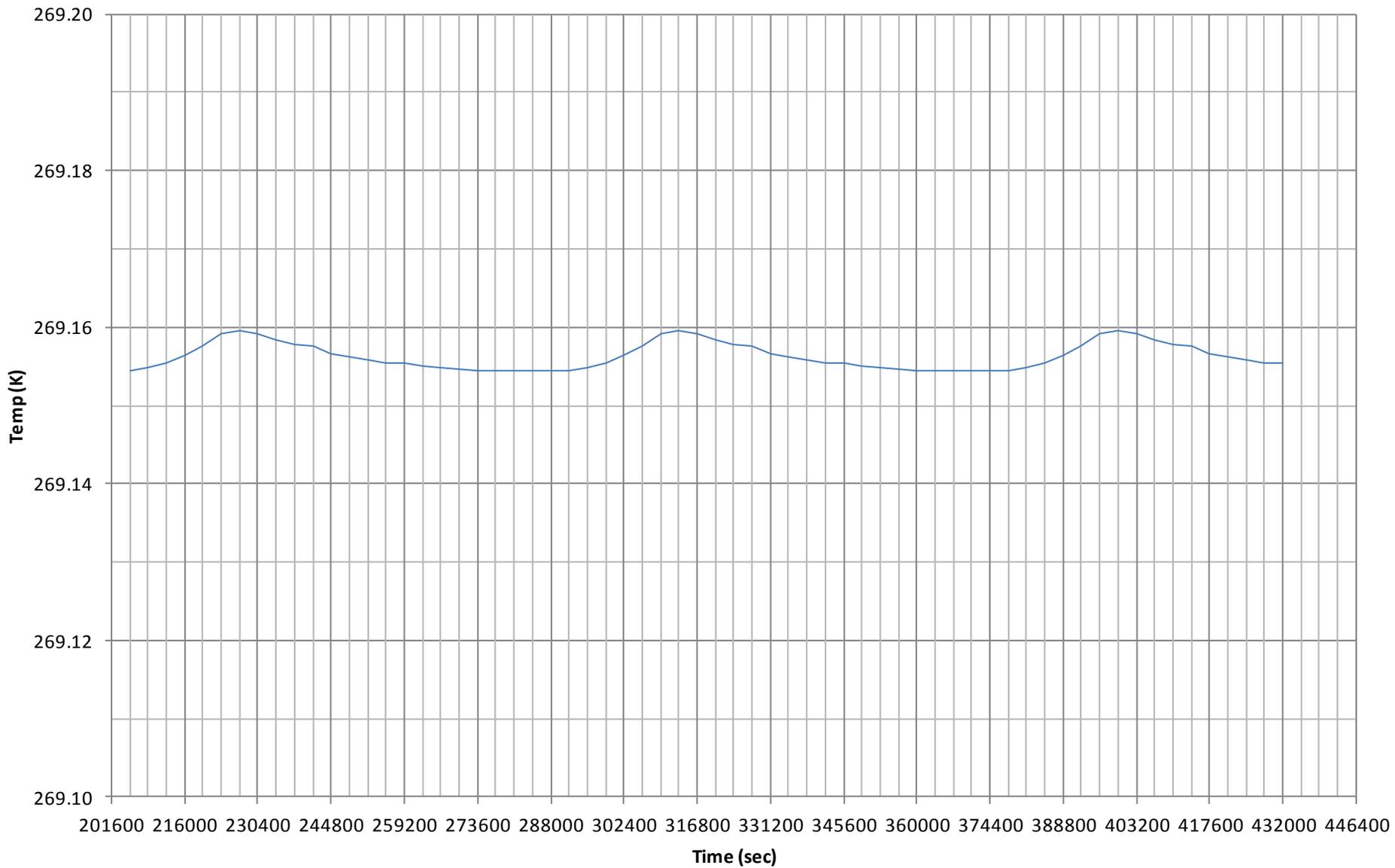
WFIRST Secondary Mirror - Front

C1V2:SM_Front



WFIRST Secondary Mirror - Back

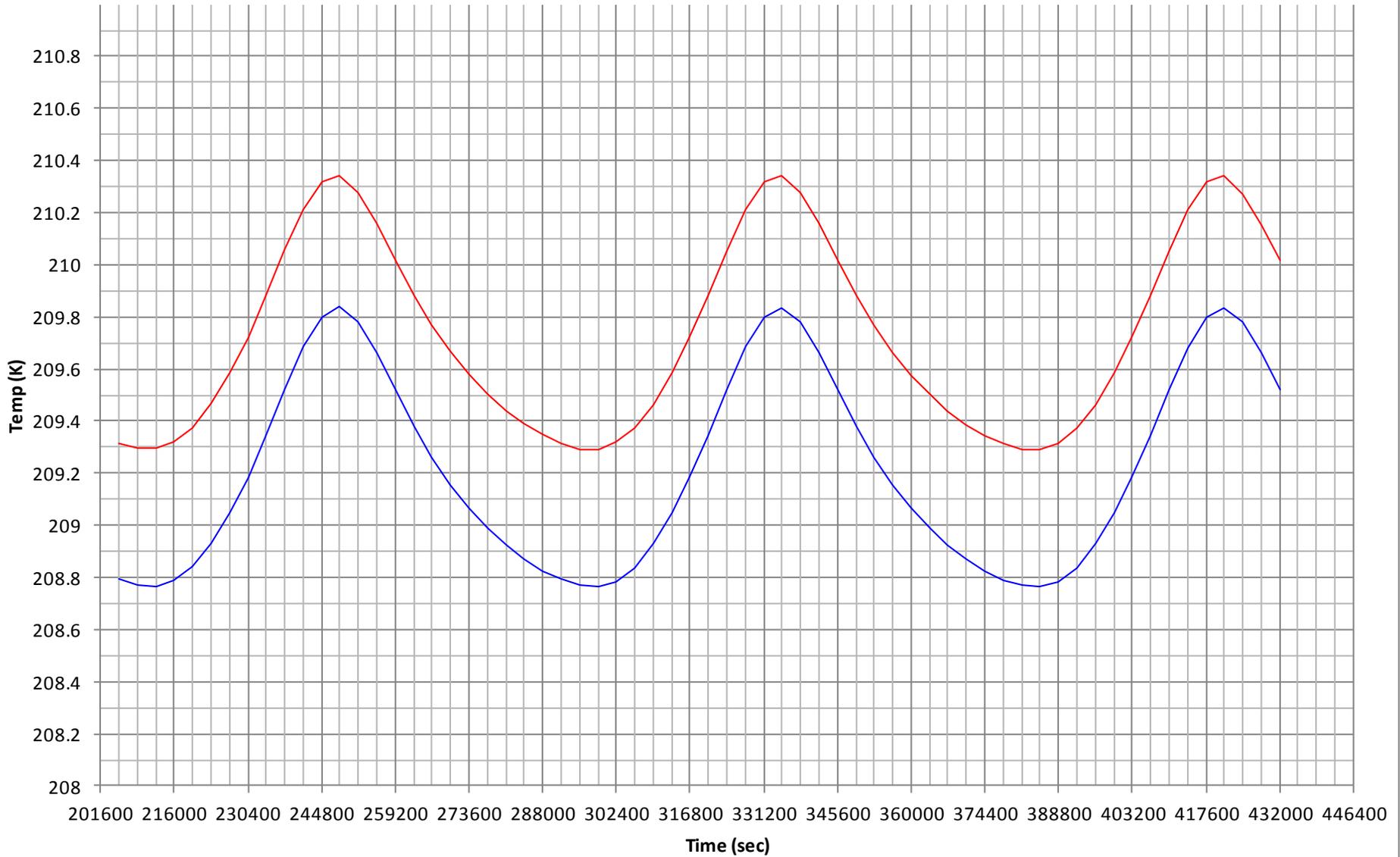
— C1V2:SM_Back



WFIRST Instrument Carrier - Deck

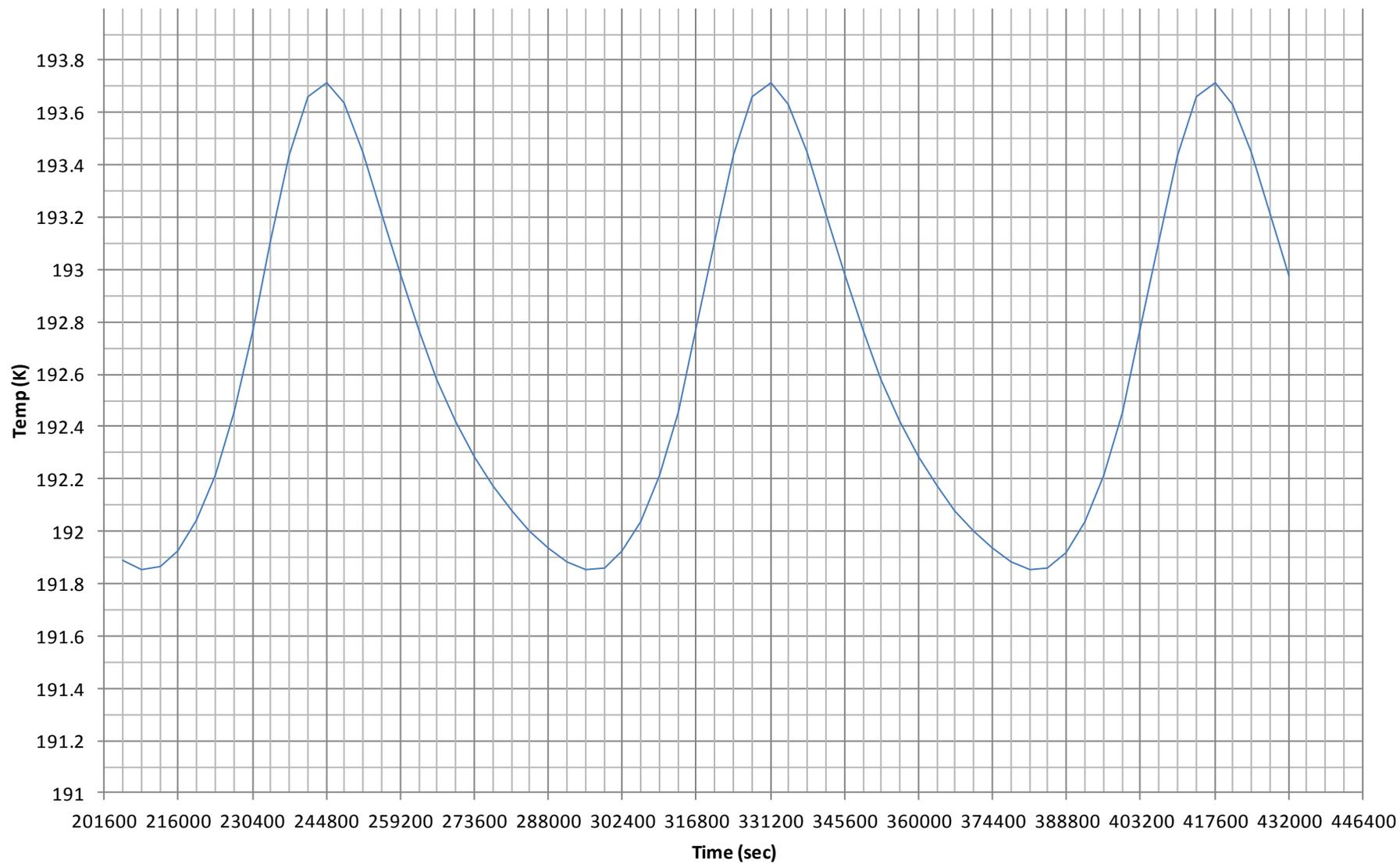
C1V2:IC_Deck_Top_FS

C1V2:IC_Deck_Bot_FS



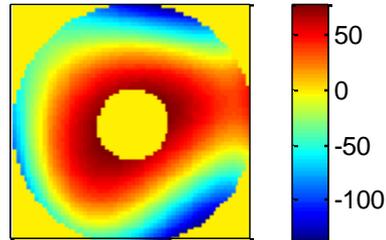
WFIRST Instrument Carrier - Tubes

C1V2:IC_Tubes

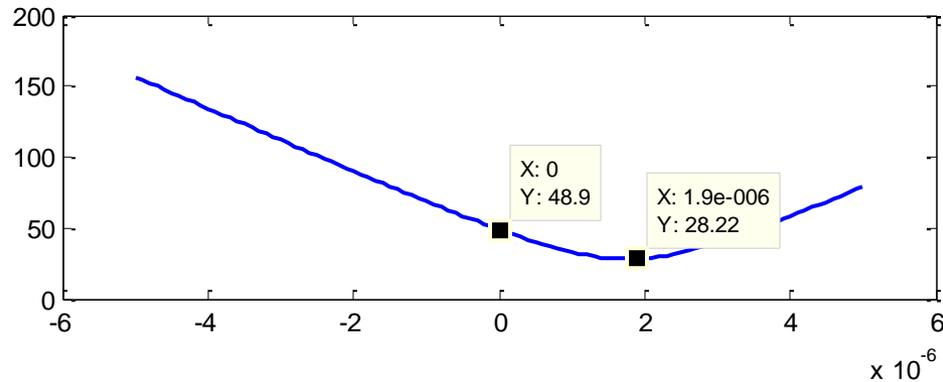
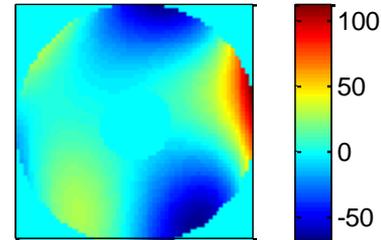


T2 Piston

PV=212.84 RMS=48.90

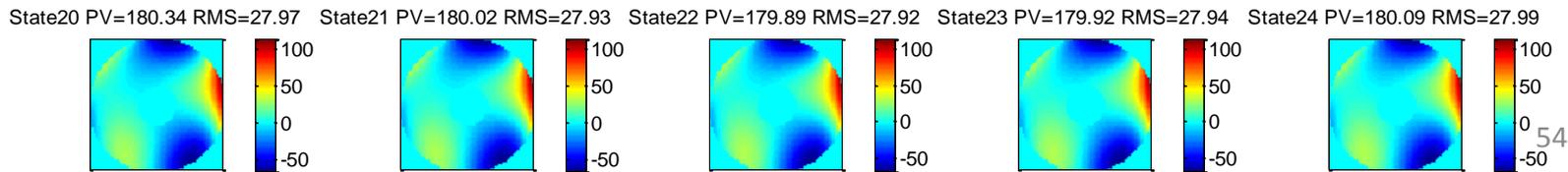
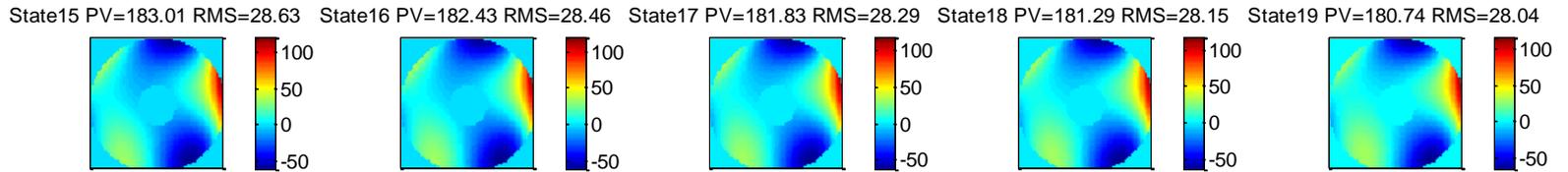
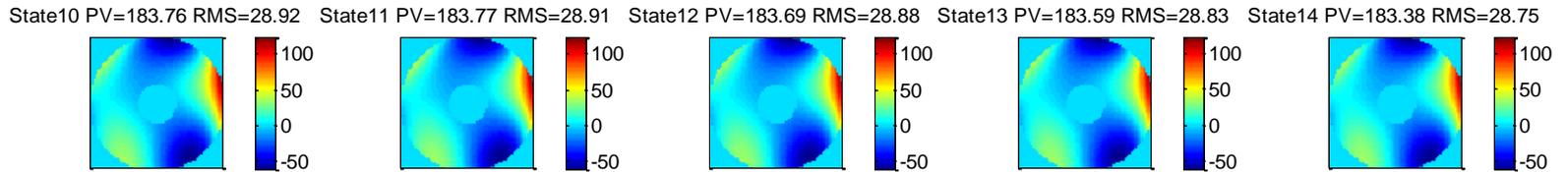
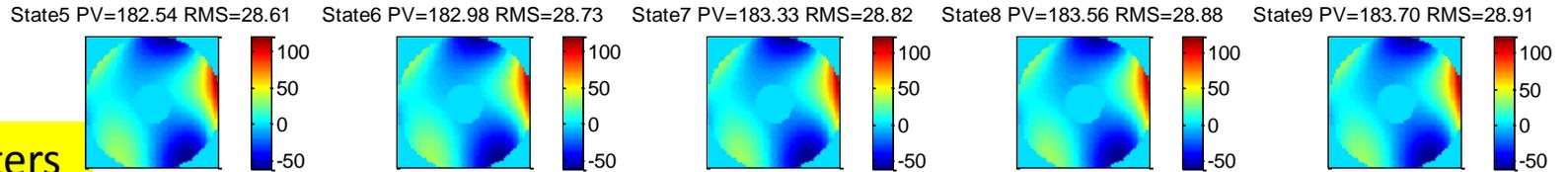
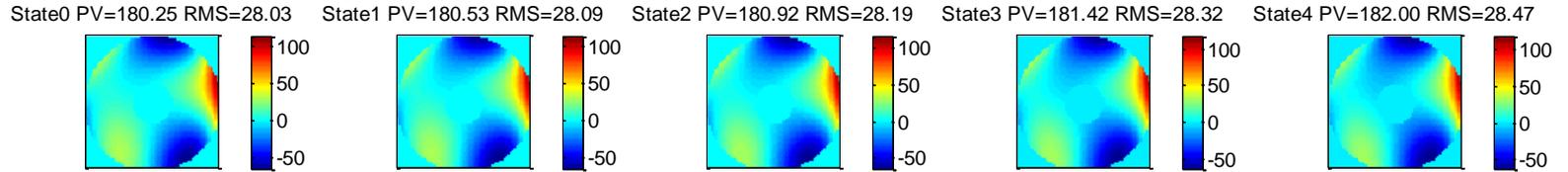


PV=180.25 RMS=28.03



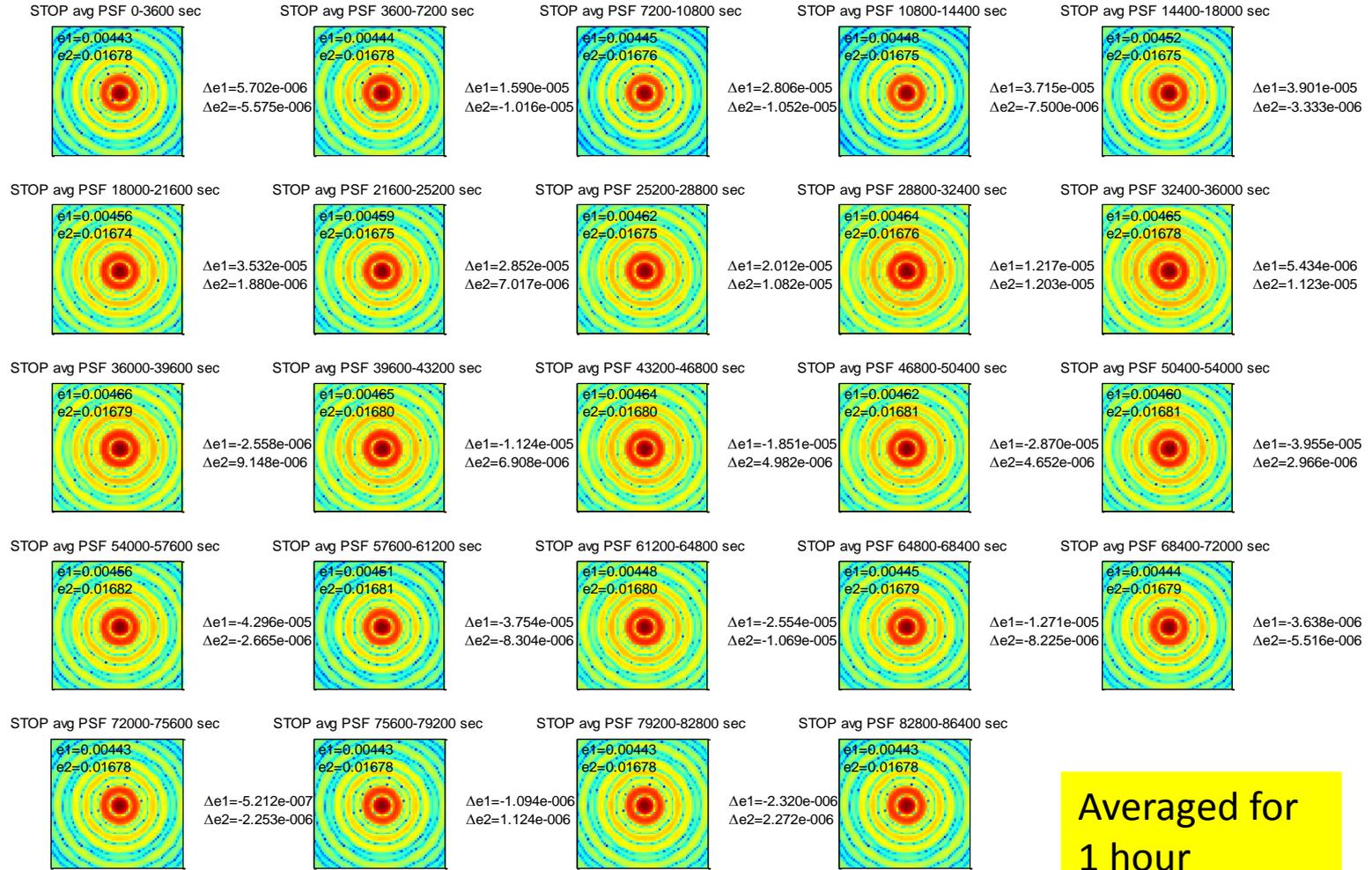
- Focus by displacing T2 in piston to minimize WFE
 - 1.76e-6 m

OPD Maps (Delta-Distortion)



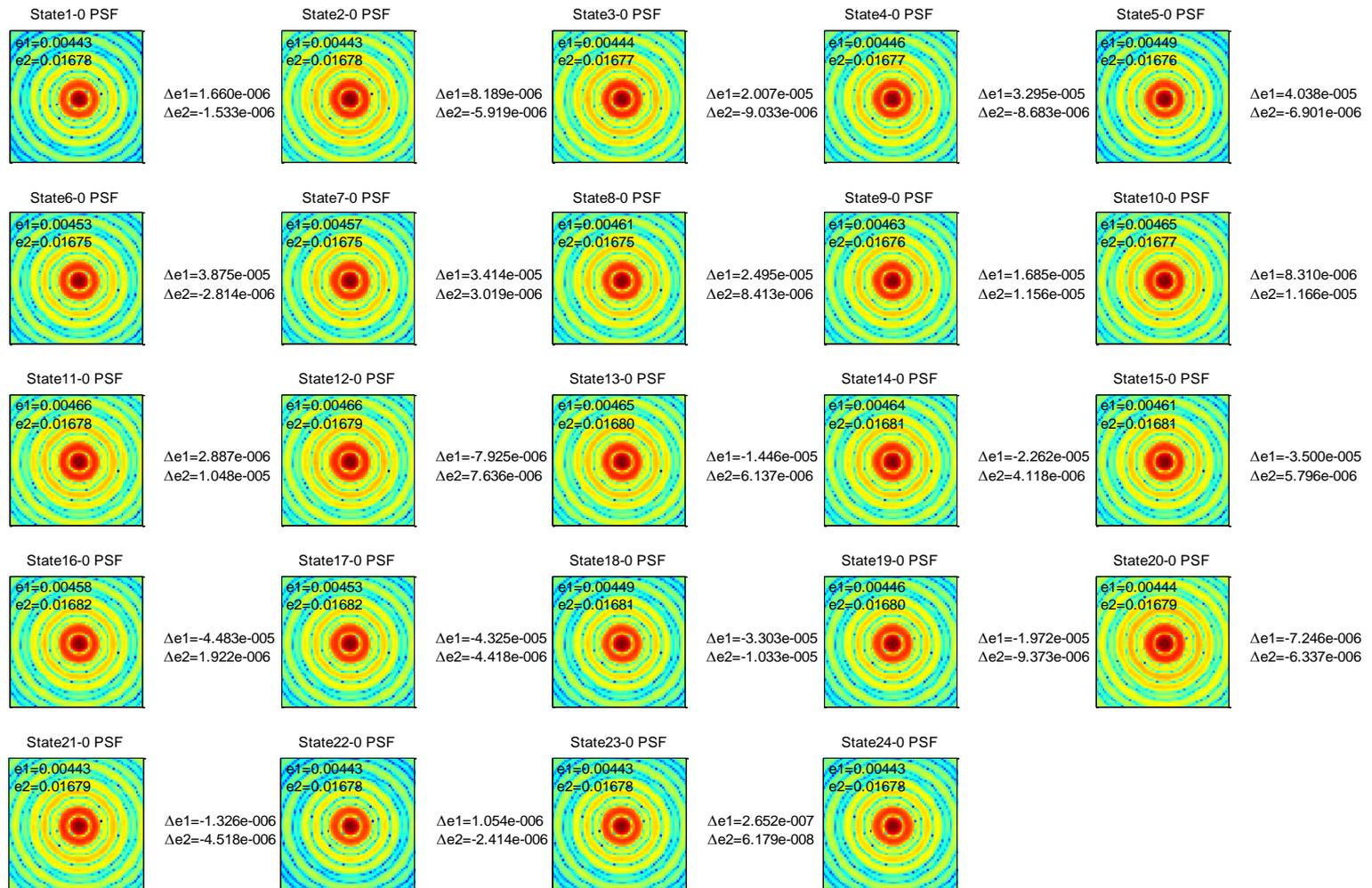
nanometers

Average PSFs



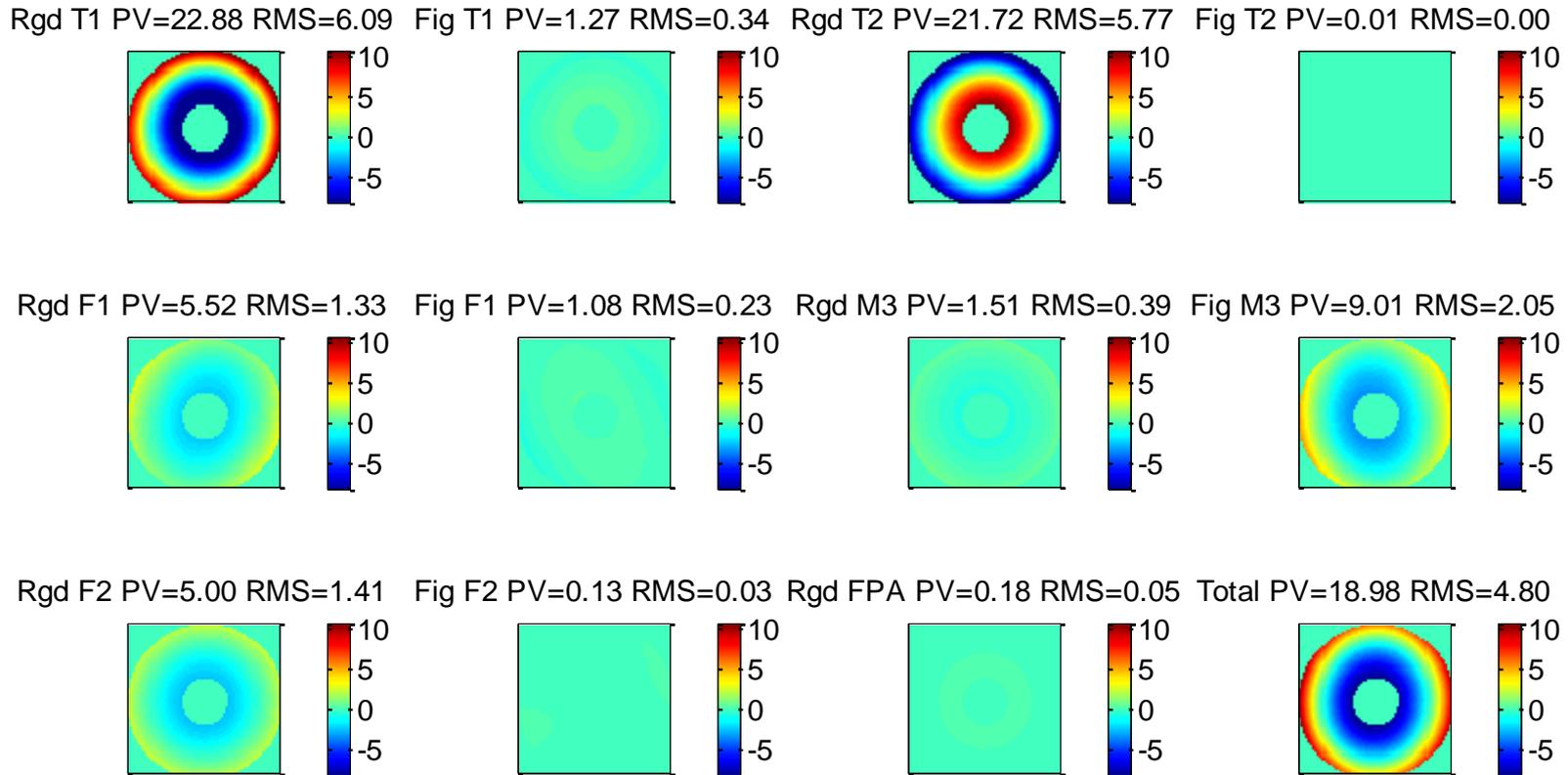
Averaged for
1 hour

PSFs (Ellipticity, delta ellipticity)



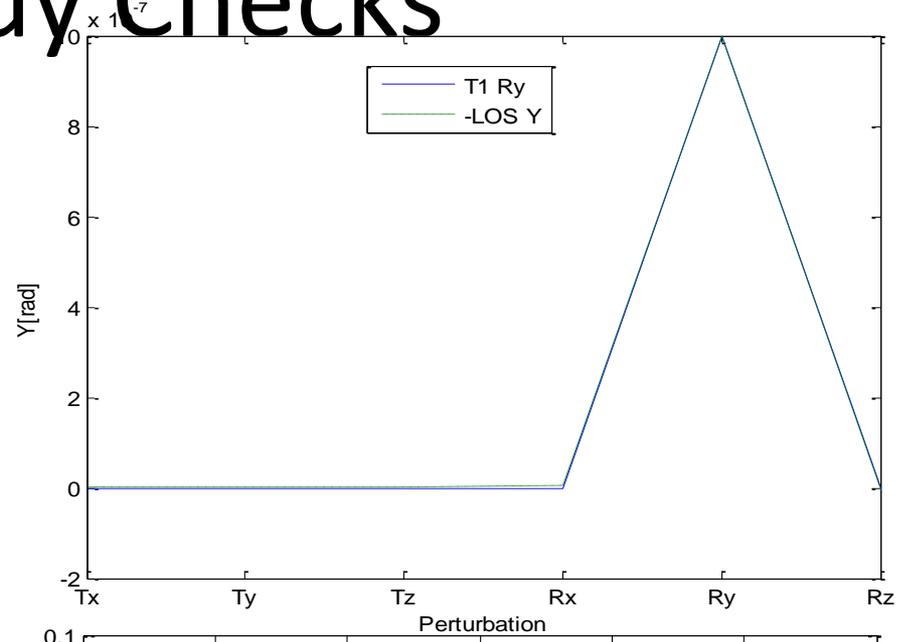
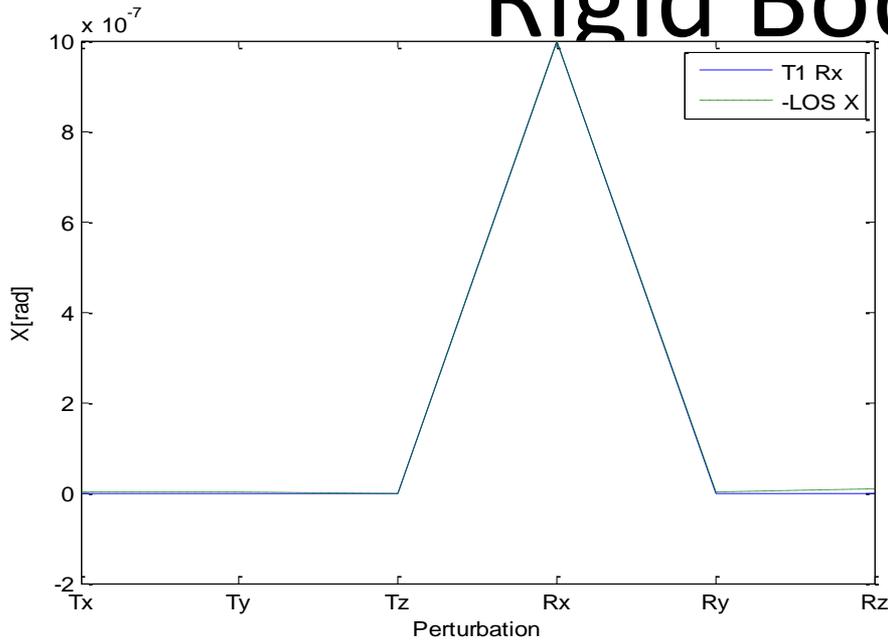
Peak is ~5nm Δwfe, ~0.00023 e1 after 11 hours; easily meets the 1nm/184 sec, 1.e-4 Δe/184 sec WFI requirements

State 11-0 OPD Map by Optic

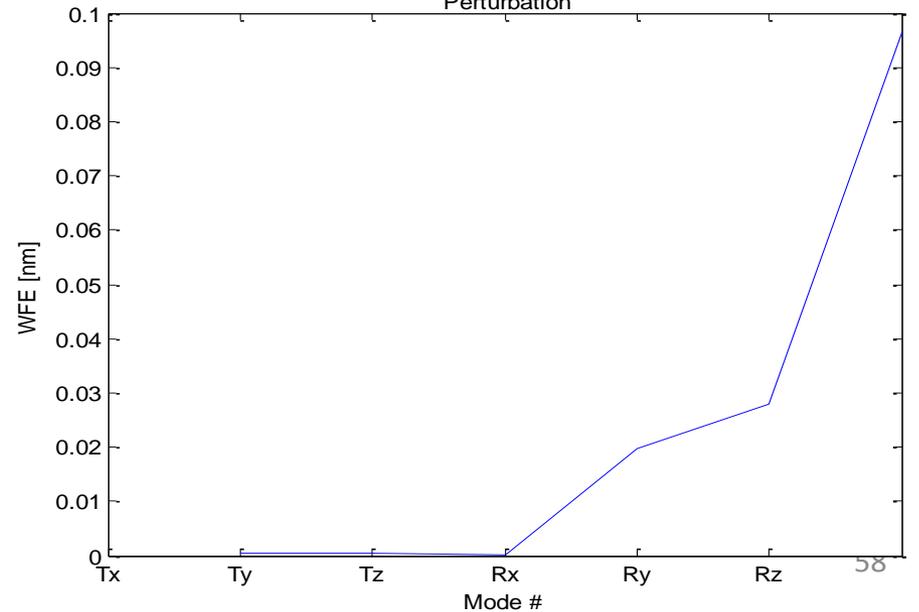


Plots show $W(\text{optic}) - W_0$. $W(\text{optic})$ is total OPD (incl static) when that optic is perturbed/figured (all other optics unperturbed) and W_0 is state 0 total OPD. Lower left plot shows the sum of all the OPD maps, and is the same as (3,2) plot on p6.

Rigid Body Checks



- 1 μ m/1 μ rad translation/rotation X/Y/Z
- LOS X, Y is identical to T1 Rx, Ry (with a sign flip) for all 6 perturbations
- WFE is ~ 0



Peak Flux Times for Tele and WFI Radiator

